PLANTERS' RECORD

VOL. XXXVIII

A quarterly paper devoted to the sugar interests of Hawaii, and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

JANUARY TO DECEMBER

THE HAWAIIAN PLANTERS' RECORD

VOL. XXXVIII

H. P. AGEE, *Editor*

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HONOLULU
1934

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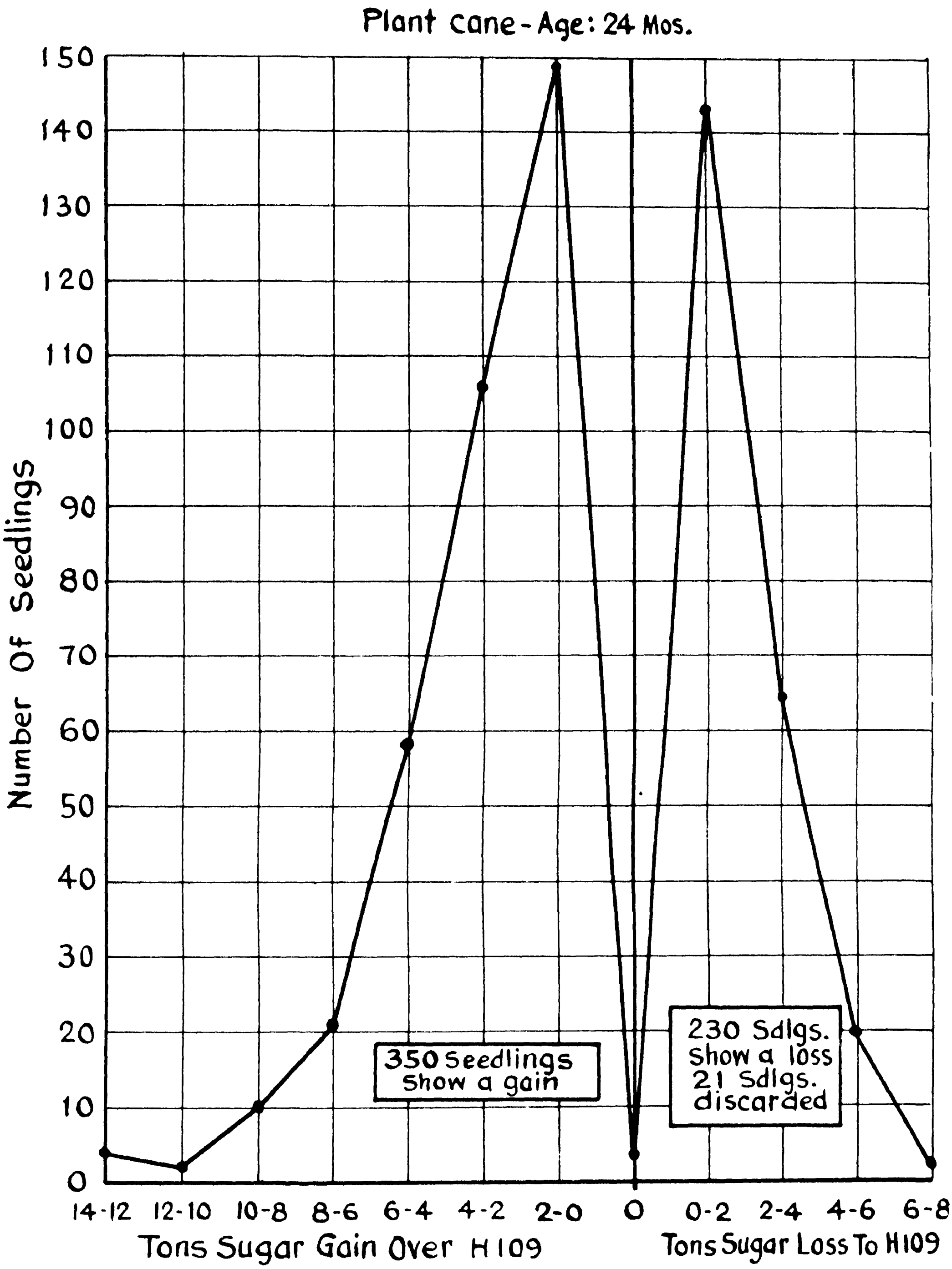
FIRST QUARTER

The growth of sugar cane may be studied to advantage in culture solutions. The above photograph shows the normal development of POJ 2878 (extreme left) and H 109 (extreme right) when grown in sand cultures for 7 months and Lahaina (two center plants) when grown in water cultures for 4 months.

SECOND QUARTER

31-1389. A promising new seedling.

THIRD QUARTER



This diagram shows the yield performance of 580 seedlings under comparison with H 109 in preliminary trials at Waipio substation. It will be noted that 350 seedlings showed various degrees of superiority over the standard cane while 230 were inferior under these first, single-plot comparisons. Such data do not permit of deductions as to the ultimate worth of the varieties tested, but are of great value in planning tests that will offer more exact comparisons.

FOURTH QUARTER

Healthy cane roots free from injury by root fungi.

5-1-59

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVIII FIRST QUARTER, 1934 No. 1

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

This number of the *Record* is devoted mainly to articles reporting studies designed to give us more detailed knowledge about sugar cane. The nutritional work now reported are primary investigations giving basic information on the mineral requirements of the cane plant, and showing the consequences upon the plant growth and structure where deficiencies are brought about under the controlled conditions of the investigations.

Another article deals with the plant under normal conditions of growth and records in great detail the performance in growth and sugar storage of normal cane under normal field conditions.

Such studies as these are necessary as the foundation structure for much that can follow in the field of plant physiology as applied to sugar cane, and ultimately in the field of sugar cane agriculture based on a better knowledge of the physiologic processes of the plant with which it deals. The articles may be more fully described as follows:

Symptoms of Nutritional Deficiencies in Sugar Cane:

The growth of sugar cane, like many other plants, may be studied to advantage in culture solutions. A nutrient solution, which contained the elements essential for plant growth, and which proved to be favorable for normal cane development was used. The methods employed for growing sugar cane plants in the culture solution are set forth.

The deficiency symptoms as manifested by the cane plant when nitrogen, iron, phosphorus, sulphur, manganese, potassium, calcium, or magnesium is omitted from the complete nutrient solution are described and illustrated. These symptoms which proved to be typical for each element may serve to distinguish similar deficiency symptoms should they appear on sugar cane grown under field conditions.

A brief account of the function of each of the eight elements in relation to plant metabolism is given.

The Sugar Cane Plant: A study of millable cane and sucrose formation.

This study was begun in March, 1931. It has important bearing upon the broad issue of cane quality, and questions of its improvement.

The study makes amply clear that for a full understanding of crop yields all the interrelated factors of field culture and of the plant itself must be properly evaluated.

Ripening it is shown is not to be considered to take place in the crop as a somewhat separate plant function from the formation of the millable cane stalk. Ripening is a continuous process taking place throughout the entire life of the plant. It is a joint by joint process. By the time the leaf attached to a joint has dried up and fallen off that joint has acquired a sucrose concentration that is close to the best that it will ever have. Under conditions that bring about fast growth, the greater use of its own sugar by the plant tends toward a lower sugar storage.

We are confronted finally with a question of balance between growth and storage, with a combination of quantity of cane and quality of juice that best serves our objective of the most profitable yield of sugar.

Here sugar cane has been studied not as a crop, nor as a plant alone, but a thoroughgoing attempt has been made to follow the process of millable cane formation and sucrose storage in the individual plants or stalks as they occur in the field as component parts of the sugar cane crop.

Boron Deficiency Symptoms in Sugar Cane:

The importance of small amounts of manganese, boron, zinc, copper, etc., to plant growth has been demonstrated in recent years by a number of students. That a minute quantity of these elements is essential for normal growth has been established by growing plants in water or in sand cultures, and in a number of instances, a marked growth response has been secured when such elements have been applied to specific soils.

The severity of many plant diseases has been directly associated with a soil condition that is unfavorable for normal plant development. A better economic control of many of the pathogenic as well as the physiological plant diseases has been effected through an understanding of the nutritional requirements of the individual plant. It is of practical importance to recognize the type of growth manifested by the plant when grown in a medium which lacks an essential element.

In the paper on boron deficiency of sugar cane, a brief review is given of the literature on the importance to plant growth of small amounts of manganese, boron, and zinc.

The deficiency symptoms which develop on cane plants grown in a minus-boron culture solution are described and illustrated. The symptoms of boron deficiency are depressed growth, the development of distorted and chlorotic leaves, and the presence of definite leaf and stalk lesions.

New Varieties of Promise:

Those who are following the new canes 28-1234 and 31-1389 will find interest in an account of some recent tests.

Symptoms of Malnutrition Manifested by the Sugar Cane Plant When Grown in Culture Solutions From Which Certain Essential Elements Are Omitted

By J. P. Martin

Contents

I. Introduction

Growth of plants is recognized by a permanent change in form, which is usually accompanied by an increase in size and weight. For growth, cell division, cell enlargement and cell differentiation are necessary; these cytological changes of the individual cells within the plant can be detected only by microscopic examination of the various plant tissues. The formation of protoplasm, a very highly organized chemical complex found within the plant cell, is of vital importance in relation to growth since such processes as photosynthesis and respiration are operations performed or induced by this chemical complex.

Such factors of environment as moisture, light, temperature and the availability in the soil of those elements essential for plant growth, govern the rate of growth and development of plants. A number of instances might be mentioned where any one of these factors has been the limiting one for normal plant growth. In commercial agriculture certain varieties are superior to others in a given locality, partly because they are better able to tolerate those peculiar conditions brought about by the existing combination of factors.

At one time, ten elements, namely, carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, iron, magnesium and sulphur, were regarded as the only elements essential for plant growth. In recent years it has been demonstrated that the presence of very small amounts of manganese, boron, iodine, zinc, copper and silica are necessary for the normal growth of certain plants.

As a rule, most of the essential elements occur in the soil in sufficient quantities for natural vegetative growth. However, when economic crops are cultivated,

it is usually necessary to apply additional plant nutrients to the soil; the kind and the amount to be supplied depending largely on the fertility of the soil and somewhat on the crop grown.

A deficiency of one or more of the essential elements in the soil may be a limiting factor for plant growth. In such cases the plants almost invariably manifest abnormalities of growth which may frequently be recognized as definite leaf or stalk symptoms of malnutrition.

The object of this paper is to describe certain deficiency symptoms artificially produced on sugar cane in culture solutions lacking nitrogen, iron, phosphorus, sulphur, manganese, potassium, magnesium or calcium, so that similar symptoms might more readily be recognized should they appear on sugar cane under field conditions.

The experiments recorded in this paper were carried out in water cultures and similar experiments were repeated in water cultures and in sand cultures. The deficiency symptoms that developed on the plants in all experiments proved to be unique for each of the eight essential elements studied. The first experiments were started August, 1932, while subsequent experiments, with the same object in view, were completed December, 1933. In this paper no attempt has been made to review the literature relevant to nutritional deficiency symptoms artificially produced on plants other than sugar cane.

II. Experimental Procedure

Three representative sugar cane varieties, namely, H 109, P. O. J. 2878 and Yellow Caledonia, were chosen for these experiments. A number of three-eye cuttings of each variety were planted in black volcanic sand and irrigated with tap water. Young shoots, from 12 to 16 inches in height, were carefully cut off from the germinated cuttings and placed in a standard nutrient solution. In most cases roots had developed on the shoots before they were removed from the cuttings. A well developed root system soon became established on the plants in the nutrient solution.

The complete or standard nutrient solution used in these studies was one which was modified from a culture solution used extensively by Dr. C. P. Sideris, Experiment Station, Pineapple Producers' Cooperative Ass'n, Ltd., and proved exceptionally favorable for the growth of sugar cane plants. The chemical composition of this solution is given in Table I, and the parts per million of each element are presented in Table II. The basic solution had a pH value of 5.2, while the pH values of the solutions in the deficiency series ranged from 4.6 to 5.8.

The plants were grown in the complete nutrient solution for six weeks. During this period the plants made an excellent growth and, no doubt, built up a reserve of the various elements before being transferred to the deficiency series. At the end of this time plants of a uniform size of each variety were selected and transferred to nutrient solutions in each of which one of the following elements was omitted: nitrogen, iron, phosphorus, sulphur, manganese, potassium, calcium and magnesium. The chemical composition of the nutrient solution in each deficiency series is also given in Table I. An attempt was made to hold the amount of each element the same in each series (Table II). The growth of the plants in

the eight deficiency series was compared with the growth of plants of similar age which were grown in the standard nutrient solution; the latter will be referred to as the control or check plants.

Distilled water and chemically pure salts were used throughout the experimental work, thus making it possible to study the growth of the plants in different media of a known chemical composition. In the deficiency series the plants were grown in the "absence" of a particular element and, no doubt, the deficiency symptoms, as manifested by the plants, developed more quickly than they would have developed under field conditions. In the fields a deficiency of an essential element frequently occurs but an absence of such an element in the soil is rare.

TABLE -1-

CONCENTRATIONS OF THE CHEMICALLY PURE SALTS PER LITER IN THE NUTRIENT SOLUTIONS.

Deficiency Series	Partial Volume Molecular Concentrations															P.P.M.*	
Elements omitted	KH_2PO_4	$NaH_2PO_4 \cdot H_2O$	KCl	KNO_3	K_2SO_4	$Ca(NO_3)_2 \cdot 4H_2O$	$NaNO_3$	$CaCl_2 \cdot 2H_2O$	$NaCl$	$CaSO_4 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	$MgCl_2 \cdot 6H_2O$	$Na_2SO_4 \cdot 10H_2O$	H_3BO_3	$Na_2SiO_3 \cdot 9H_2O$	$FeSO_4(NH_4)_2SO_4 \cdot 6H_2O$	$MnSO_4$
Complete Soln.	.001			.003		.003		.004			.001			.00002	.00001	10	.25
Nitrogen	.001				.0015			.0035			.001			.00002	.00001	10	.25
Phosphorus			.001	.003		.003		.004		.001	.001			.00002	.00001	10	.25
Potassium		.001				.003	.003	.004		.001	.001			.00002	.00001	10	.25
Calcium	.001			.003			.006		.002		.001			.00002	.00001	10	.25
Magnesium	.001			.003		.003		.004					.001	.00002	.00001	10	.25
Sulphur	.001			.003		.003		.004				.001		.00002	.00001	10[A]	.25[B]
Manganese	.001			.003		.003		.004			.001			.00002	.00001	10	
Iron	.001			.003		.003		.004			.001			.00002	.00001		.25

Ⓐ Fe from Ferric Citrate * P.P.M. = parts per million of Fe or Mn. Ⓑ Mn from Manganous Chloride.

TABLE -II-

PARTS PER MILLION OF EACH ELEMENT USED IN EACH OF THE NINE CULTURE SOLUTIONS.

Deficiency Series	N	P	K	Ca	Mg	S	Mn	Fe	Na	Cl	Si	B
Control	126	31	156	280	24	32	.25	10	.23	284	.28	.216
Nitrogen	—	31	156	140	24	80	.25	10	—	249	.28	.216
Phosphorus	126	—	156	320	24	64	.25	10	—	319	.28	.216
Potassium	126	31	—	320	24	64	.25	10	92	284	.28	.216
Calcium	126	31	156	—	24	32	.25	10	184	71	.28	.216
Magnesium	126	31	156	280	—	32	.25	10	46	284	.28	.216
Sulphur	126	31	156	280	24	—	.25	10	—	355	.28	.216
Manganese	126	31	156	280	24	32	—	10	.23	284	.28	.216
Iron	126	31	156	280	24	32	.25	—	.23	284	.28	.216

The containers used for growing the sugar cane plants were one-gallon earthenware jars with glazed inner surfaces. A two-piece cover, made of redwood, fitted over each jar. Each plant was held in an upright position by placing two halves of a large cork around it and then by placing the cork and the plant as a unit tightly into a circular hole in the cover. With this arrangement the plants could easily be adjusted and the root systems readily examined at all times. All experimental work was conducted in a large greenhouse in order to avoid adverse climatic conditions that might interfere with the experiments.

The various nutritional deficiency series, as well as the complete or control series, were started September 22, 1932. At first, the nutrient solutions were changed once a week but, as the plants developed, it was necessary to renew the solutions once every four or five days. On December 12, 1932, a photograph of the plants in each series was taken (Figs. 1, 3, 5, 7, 9, 11, 13, 15 and 17). It will be noted from these photographs that the growth of all plants in each series was fairly uniform. The cane varieties that were grown in the various series are indicated in the photographs. Many of the plants at this time, i. e., at the end of 80 days, manifested definite deficiency symptoms, which are described in detail later.

The plants were allowed to continue to grow in the deficiency series until February 24, 1933, a period of 152 days. On this date one H 109 cane plant in each deficiency series, except the minus-iron series, was transferred to the complete nutrient solution. On April 28, 1933, or after an interval of 216 days, the plants in each series were again photographed (Figs. 2, 4, 6, 8, 10, 12, 14, 16 and 18). The plant on the right in each photograph, except in Fig. 2, shows the rapid

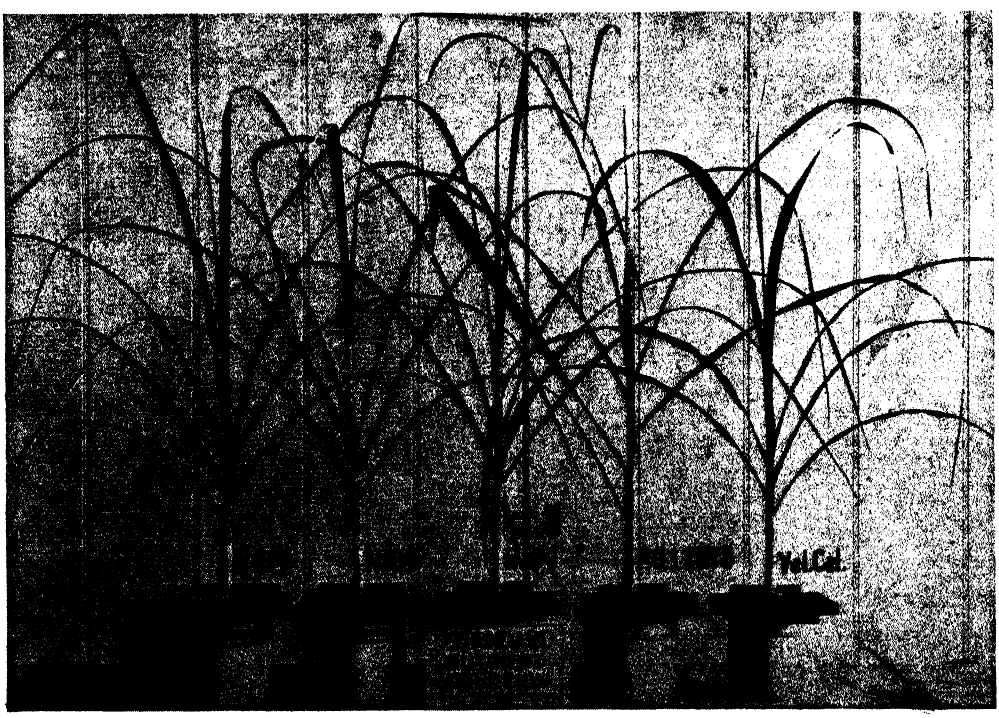


Fig. 1. Control plants, age 80 days. These plants were grown in the complete or standard nutrient solution and appeared normal in every respect.

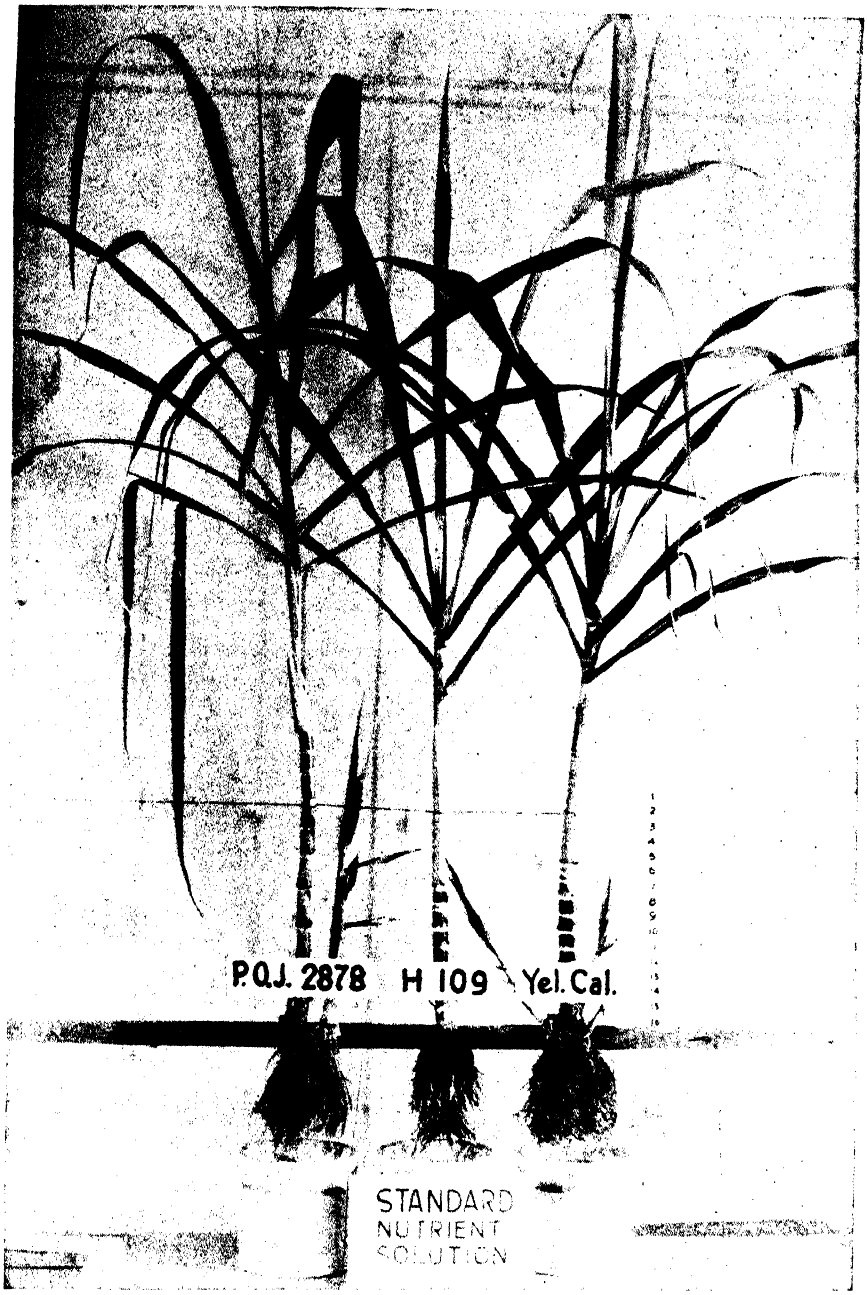


Fig. 2. Control plants, age 216 days. The plants at all times exhibited a normal color and made a uniform growth. Considerable root injury from *Pythium* root rot occurred, as shown by the reduced root development on the individual plants.

recovery and the normal growth made as a result of the addition of the missing element; the other plants show a markedly depressed growth in contrast to the H 109 plant on the right and to the control plants (Fig. 2).

Shortly before the plants were photographed, April 28, 1933, one or two plants were selected from each series for microchemical tests. These tests showed a deficiency in the tissues of the leaves and stalks of the element lacking in each deficiency series.

A description of the nutritional deficiency symptoms, as manifested by these plants as a result of faulty nutrition, is given under each of the eight elements studied. As already mentioned, the growth of the cane plants in the various deficiency series was at all times compared with the growth of the control plants, which made what was assumed to be a normal growth throughout the experiment (Figs. 1 and 2).

A brief account of the functions of each of the eight elements in relation to plant metabolism is also presented under its respective heading. The information pertaining to the function of each element has been taken largely from publications dealing with plants other than sugar cane but, in general, such information should be applicable to the sugar cane plant. An understanding of the function of an element explains, in a number of cases, why certain symptoms are characteristic of the deficiency of that particular element.

III. Interpretation of Results

Nitrogen

Deficiency Symptoms: In the minus-nitrogen series, the first evidence of any physiological change in the young leaves of the plants was the development of a yellow-green color or chlorosis. This was observed from 2 to 4 weeks after the nitrogen had been omitted from the solution. At the end of 5 to 8 weeks, all leaves were of a uniform pale yellow-green color in contrast to the dark green color of the leaves on the control plants.

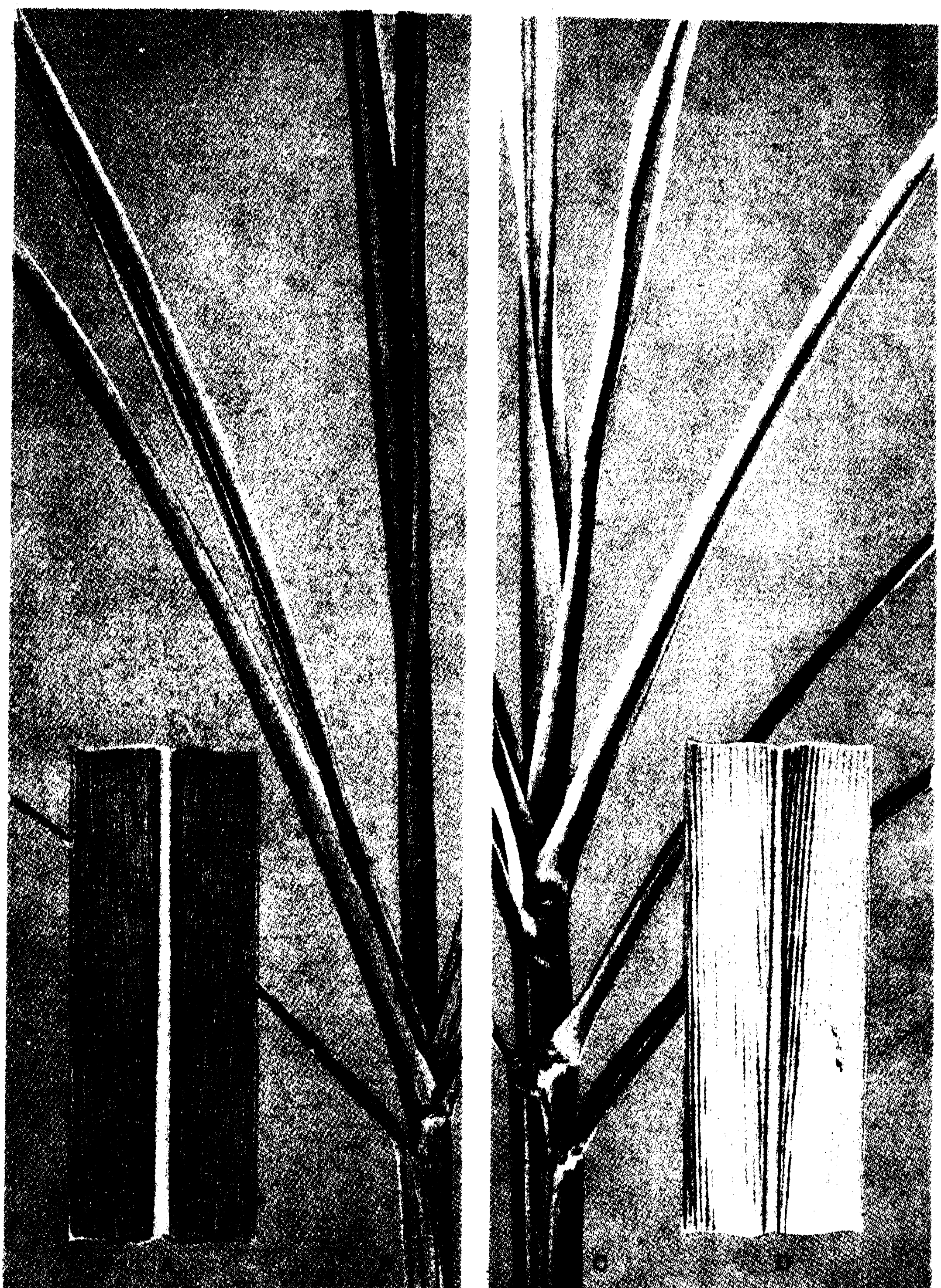
The leaf tips and margins of the older leaves began to dry prematurely, the dried portions assuming a light-brown or straw color. The mature leaves died much sooner than leaves of the same age on the control plants. No leaf markings other than this drying of the edges developed.

The growth, or further elongation, of the primary stalks soon came to a standstill. All the leaves appeared as though they had developed from a common point, a definite characteristic of a cane plant that is not growing (Fig. 4). These depressed stalks, or stems, were characterized by being slender and of a light red color. This color change was particularly noticeable on the variety H 109.

The roots appeared to have been stimulated in growth. They attained a much greater length but were smaller in diameter than the roots of the control plants. The root system of each plant completely filled the jar and was extremely free from *Pythium* root rot (Fig. 4).

Upon the addition of nitrogen to the minus-nitrogen series, a definite color and growth response was visible within 15 days (Fig. 4); it may also be observed that the root system of the H 109 plant on the right has lost its compactness fol-

PLATE I



A, B—Nitrogen Deficiency
C, D—Iron Deficiency

lowing the addition of nitrogen. This condition is due largely to the breaking down of the individual roots from *Pythium* root rot. Carpenter (1), in 1928, demonstrated that the severity of *Pythium* root rot on cane varieties grown in the soil increases with increased applications of nitrogen. Of all the deficiency series, the cane plants in the minus-nitrogen series manifested the most rapid recovery when the limiting element was added.

Nitrogen-deficiency symptoms of sugar cane under field conditions in Hawaii have been described by Naquin (14) and in culture solutions in Java by van den Honert (16).

The symptoms of nitrogen deficiency are shown in Figs. 3 and 4 and also in Plate I, where they are shown in color.

The Function of Nitrogen: Nitrogen is one of the constituents of the chlorophyll molecule and its presence is, therefore, essential for the formation of chlorophyll or the green coloring matter in plants. Chlorophyll has the power to combine the carbon dioxide and water within the leaf, utilizing the sun's rays or light energy to form carbohydrates among which are various forms of sugars. This process is known as photosynthesis (a putting together of raw materials by light energy).

Nitrogen combines with carbohydrates to form proteins which, in turn, enter largely into the making of protoplasm. Proteins are complex compounds containing hydrogen, oxygen, nitrogen, sulphur and sometimes phosphorus in addition to carbon. Gelatine and egg white are almost pure proteins. Protoplasm is what might be termed the only living part of the plant and is found within certain

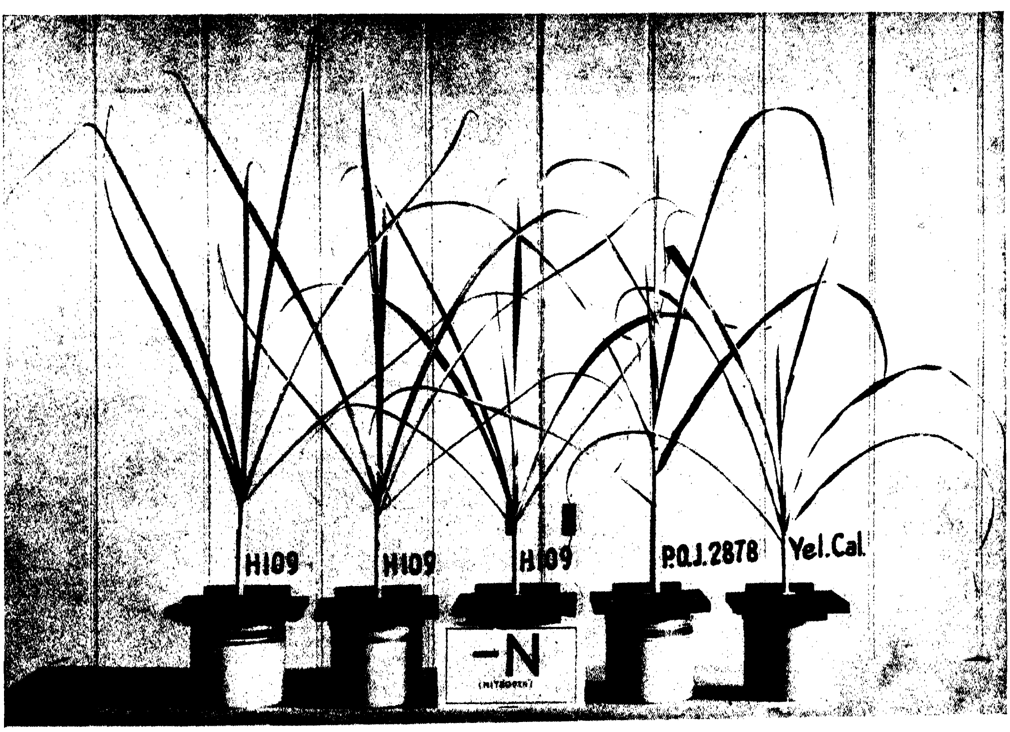


Fig. 3. Minus-nitrogen series, at the end of 80 days. Note small diameter of stalks and depressed growth as compared with the control plants (Fig. 1). Definite leaf and stalk symptoms of nitrogen deficiency appeared on these plants.

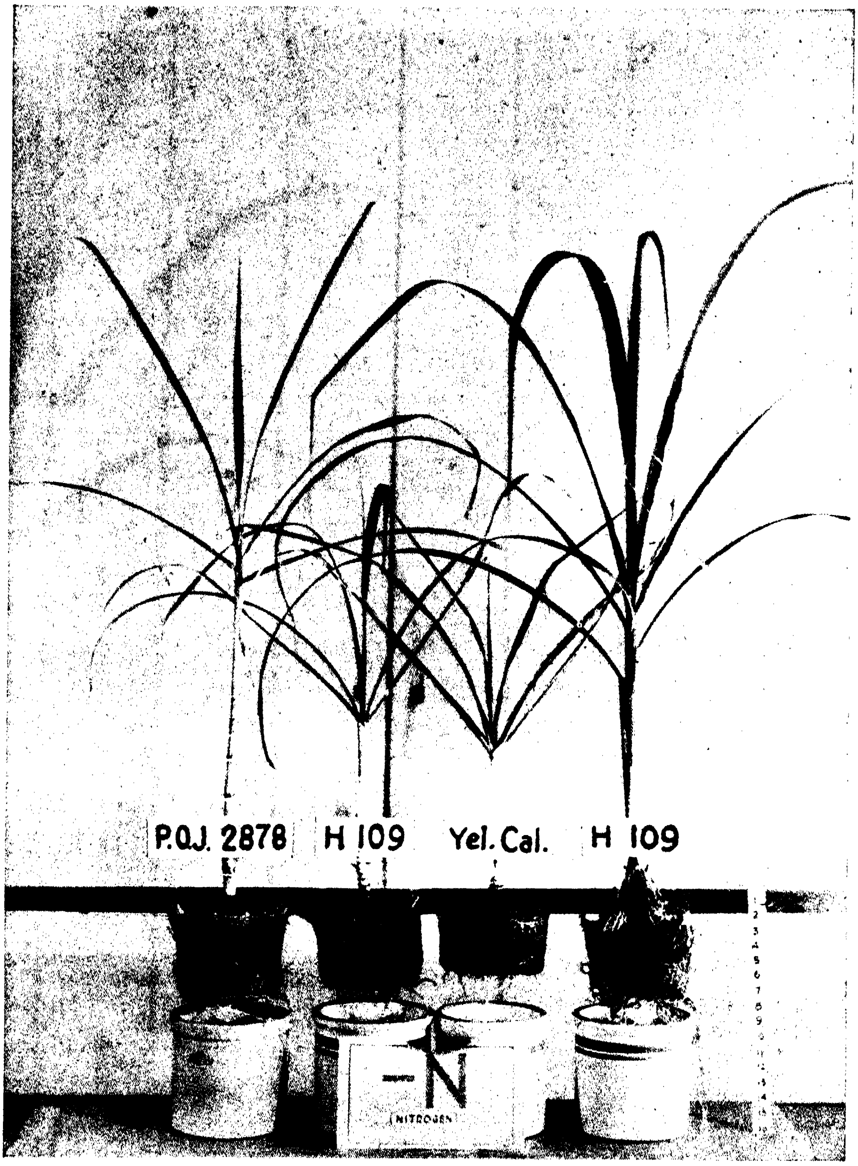


Fig. 4. Minus-nitrogen series, at the end of 216 days. Note greatly depressed growth as shown by the narrow leaves, slender stalks and shortened internodes. The root systems were very compact and free from *Pythium* root rot. The individual roots were smaller in diameter than those on the control plants. Nitrogen was again added at the end of 152 days to the solution in which the H 109 plant on the right had been growing. A definite color and growth response was visible within 15 days. The root system on this particular plant began to lose its compactness as a result of *Pythium* root rot.

plant cells. Chemically, protoplasm consists of carbohydrates, water, fats, proteins and a number of the mineral elements such as calcium, potassium, phosphorus, sulphur and iron.

With an abundance of carbohydrates and nitrogenous compounds, vegetative growth is greatly increased. If nitrogen is lacking the carbohydrates continue to accumulate, the leaves begin to develop a chlorotic condition and growth is retarded. If such a condition continues the symptoms become more acute and the plants die.

For normal growth of sugar cane a continuous supply of nitrogen is essential, as briefly explained above. If, however, as the cane plant approaches maturity, the supply of available nitrogen is decreased, the plants become chlorotic, indicating a retardation of vegetative growth and an accumulation of carbohydrates, which conditions are to be desired at this time. Of all the elements essential for plant growth, nitrogen, no doubt, has the greatest effect on cane ripening and juice quality.

Iron

Deficiency Symptoms: In the various deficiency series perhaps the most definite as well as the most easily recognized diagnostic symptoms developed on the plants which were placed in the minus-iron solution.

At the end of 2 or 3 weeks, a pale striping appeared on the young leaves, later becoming very pronounced. The alternating dark green and chlorotic-to-white stripes extended the entire length of the leaves. The normal green color first disappeared from the leaf tissues between the small vascular bundles, leaving green

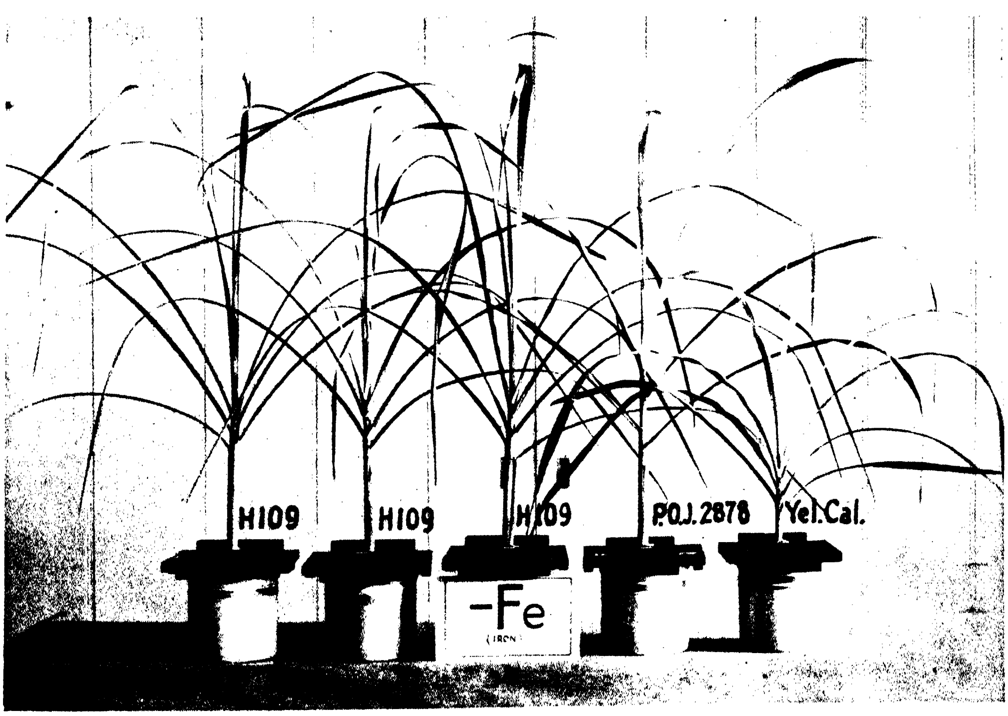


Fig. 5. Minus-iron series, at the end of 80 days. At this time, the growth of the plants was slightly retarded and definite leaf symptoms of iron deficiency were present.

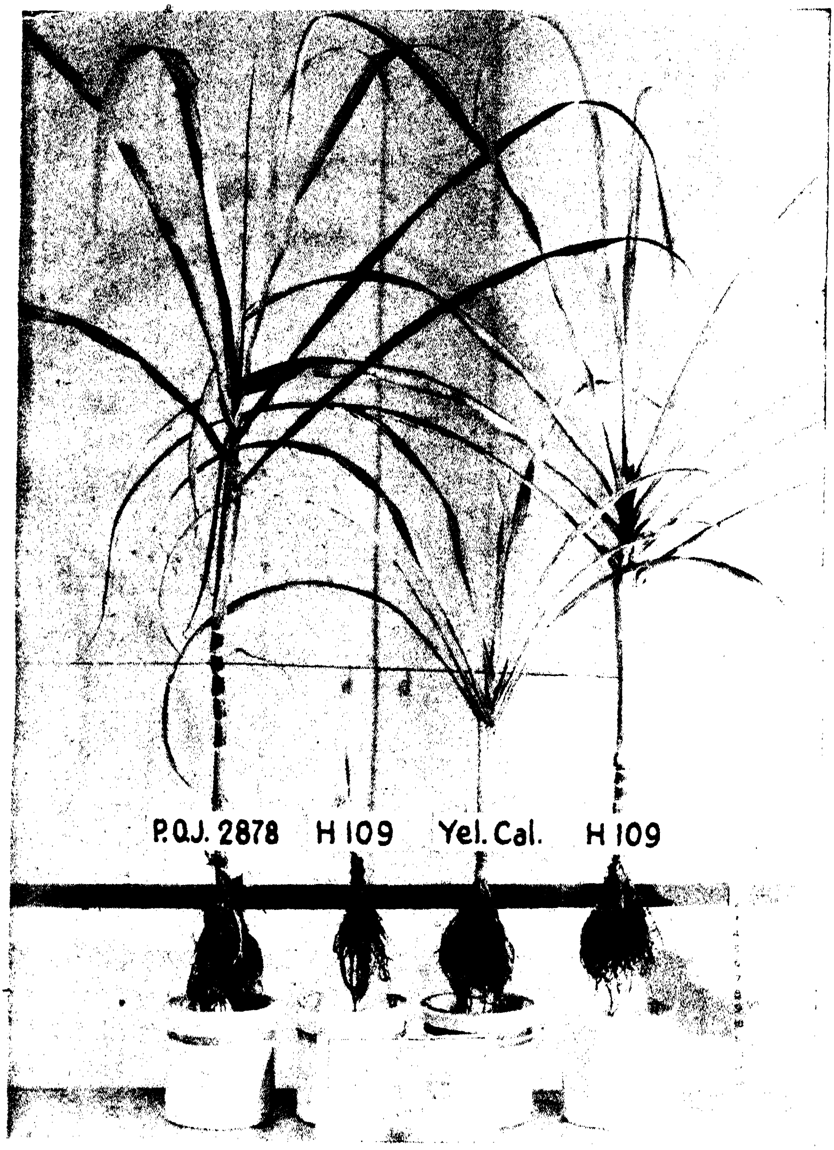


Fig. 6. Minus-iron series, at the end of 216 days. Note the condition of the two center plants which were deprived of iron. The two plants on the ends were sprayed, at the end of 95 days, with a 2 per cent solution of iron sulphate. This treatment corrected the chlorotic condition of the plants for a limited time. Five to six weeks later, these two plants again manifested symptoms of iron deficiency, as shown in the photograph. The roots were severely attacked with *Pythium* root rot and showed the abnormal or "stubby" type of growth as described in the text.

only the chlorophyll-bearing tissues immediately surrounding the large bundles, thus giving the striping effect. Later, this tissue immediately surrounding the large vascular bundles also became chlorotic, rendering the striping less conspicuous and resulting in a more uniformly pale or chlorotic appearance. During this period the older leaves on the plants retained their original dark green color.

Within 6 to 8 weeks, the new leaves were perfectly white except for a trace of light green color in the lower surfaces of the midribs. On leaves unrolling later, no trace of any green color was present (Fig. 5).

There was a strong contrast between the young leaves which were white and the intermediate leaves which were only partially green and still a greater contrast between these young leaves and the old leaves which were of a dark green color. Since only the new growth of the plants in the iron-free solution became chlorotic, this is an indication that iron does not move from the older to the younger parts of the plant.

Two of the plants showing acute iron-deficiency symptoms were sprayed with a 2 per cent solution of iron sulphate, December 27, 1932. A definite greening of the leaves was apparent within 3 or 4 days and at the end of 14 days the plants were of a normal green color. This one treatment corrected the chlorotic condition for 4 to 6 weeks and following this period the new leaves again began to manifest characteristic symptoms of iron deficiency (Fig. 6). The plants which received no additional iron were greatly depressed in growth and soon died (Fig. 6).

The roots of the iron-deficient plants developed an abnormal type of growth, which later proved to be characteristic of plants growing in a minus-iron medium. The growth of the primary roots was greatly retarded; the secondary roots as well as those of the third order were extremely short or "stubby" in growth. A large number of roots were killed by *Pythium* root rot, indicating that an "unbalanced" solution is favorable for the development of this disease.

The symptoms of iron deficiency are shown in Figs. 5 and 6 and in Plate 1.

The Function of Iron: Although iron is not a component part of the chlorophyll molecule, it is, however, essential for the formation of chlorophyll in plants. Iron apparently acts as a catalyst in the formation of chlorophyll.

The leaves and stems of plants deprived of iron develop a pale or yellow condition which is known as "chlorosis." If iron is not supplied to chlorotic plants they prematurely die. In water cultures, only small quantities of iron are necessary for normal plant growth.

Phosphorus

Deficiency Symptoms: The cane plants in the minus-phosphorus solution continued to make a normal growth for 6 to 8 weeks. At the end of this time, a slowing up of the growth of the plants was observed (Fig. 7). The newer leaves were narrower in proportion to their length and developed a trace of a greenish-blue color, more noticeable when compared with the dark green color of the leaves on the control plants. Toward the end of the experiment the leaves manifested a slight yellowish-green color. The stalks became slender, a shortening of the internodes was noted and growth in general was greatly retarded (Fig. 8).

The older leaves showed a definite drying and dying at the tips but not as pronounced as the older leaves on the plants in the minus-nitrogen or minus-potassium series. No spotting or striping developed on the leaves.

The roots were decidedly brownish in color and were badly affected with *Pythium* root rot. In recent studies it has been shown that cane roots when grown in water cultures deficient in phosphorus are more susceptible to *Pythium* root rot. Cooke (3) and Carpenter demonstrated that sugar cane is much more susceptible to *Pythium* root rot when grown in soils deficient in phosphorus.

When phosphorus was returned to the minus-phosphorus solution the plants showed a rapid recovery both in color and growth (Fig 8). The diameter of the stalks began to enlarge, the internodes became longer and the leaves became wider and of a normal dark green color.

At no time during the experimental studies were the symptoms of phosphorus deficiency so definite or clear cut as were the deficiency symptoms of the other seven elements. According to the writer's experience, phosphorus-deficiency symptoms as they occur under field conditions are the most difficult ones to recognize. In order to confirm a diagnosis of phosphorus deficiency in the field, it would be advisable to resort to microchemical analyses of plant tissue or to chemical and biological tests of the soil.

Naquin (14), in 1926, described the symptoms of phosphorus deficiency of sugar cane as they appeared under field conditions. In 1932, van den Honert (16), in Java, described phosphorus-deficiency symptoms of sugar cane when grown in culture solutions.

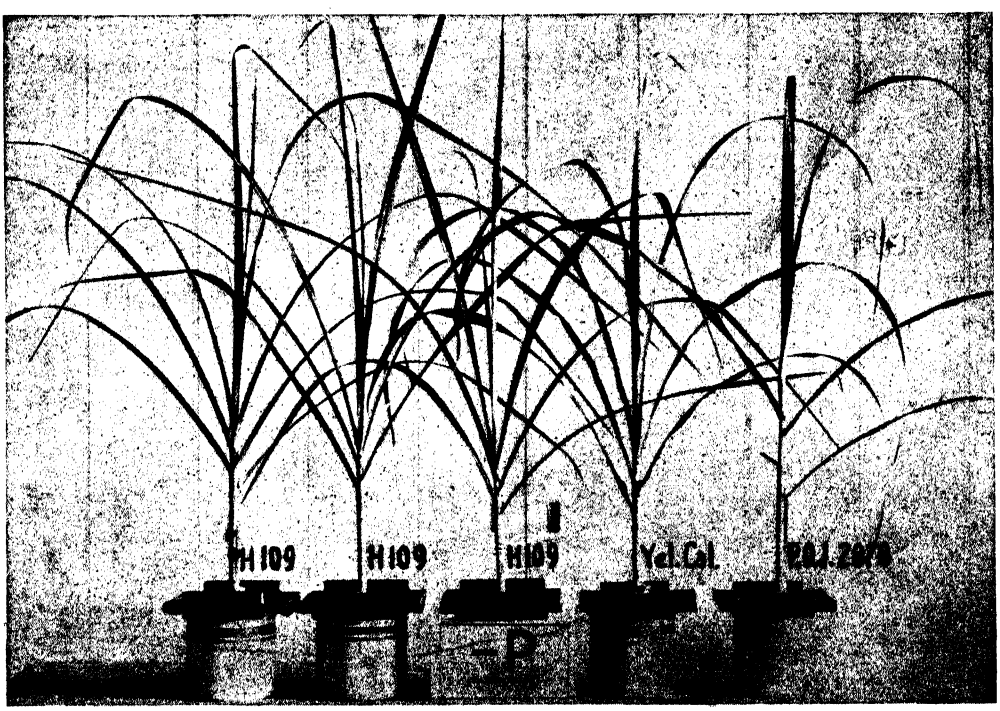
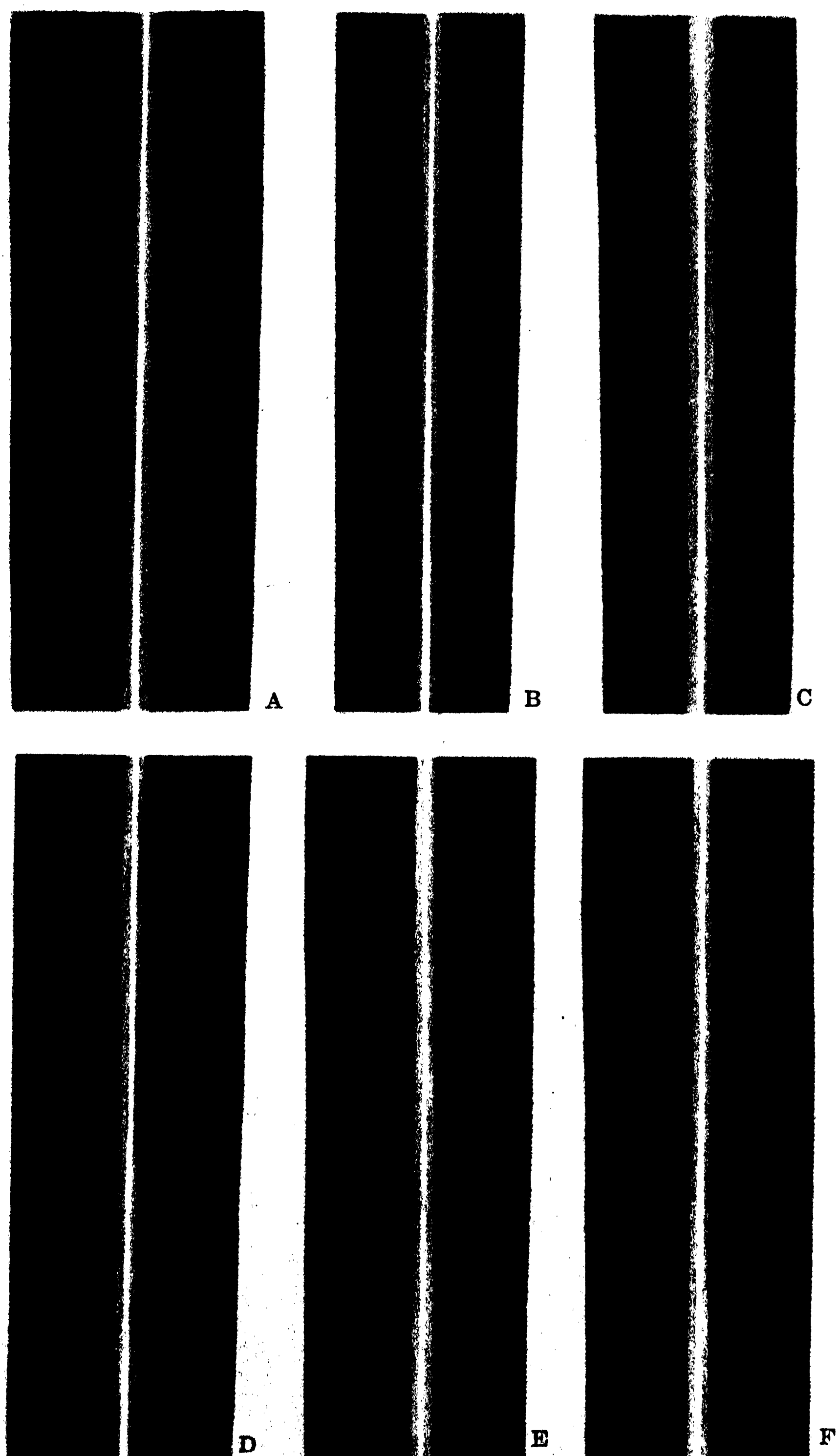


Fig. 7. Minus-phosphorus series, at the end of 80 days. The leaves were of a greenish-blue color in contrast to the normal dark green color of the leaves on the control plants. The growth of the plants was slightly less than that of the control plants (Fig. 1).

PLATE II



A, D—Normal Leaves
B, C—Phosphorus Deficiency
E, F—Sulphur Deficiency

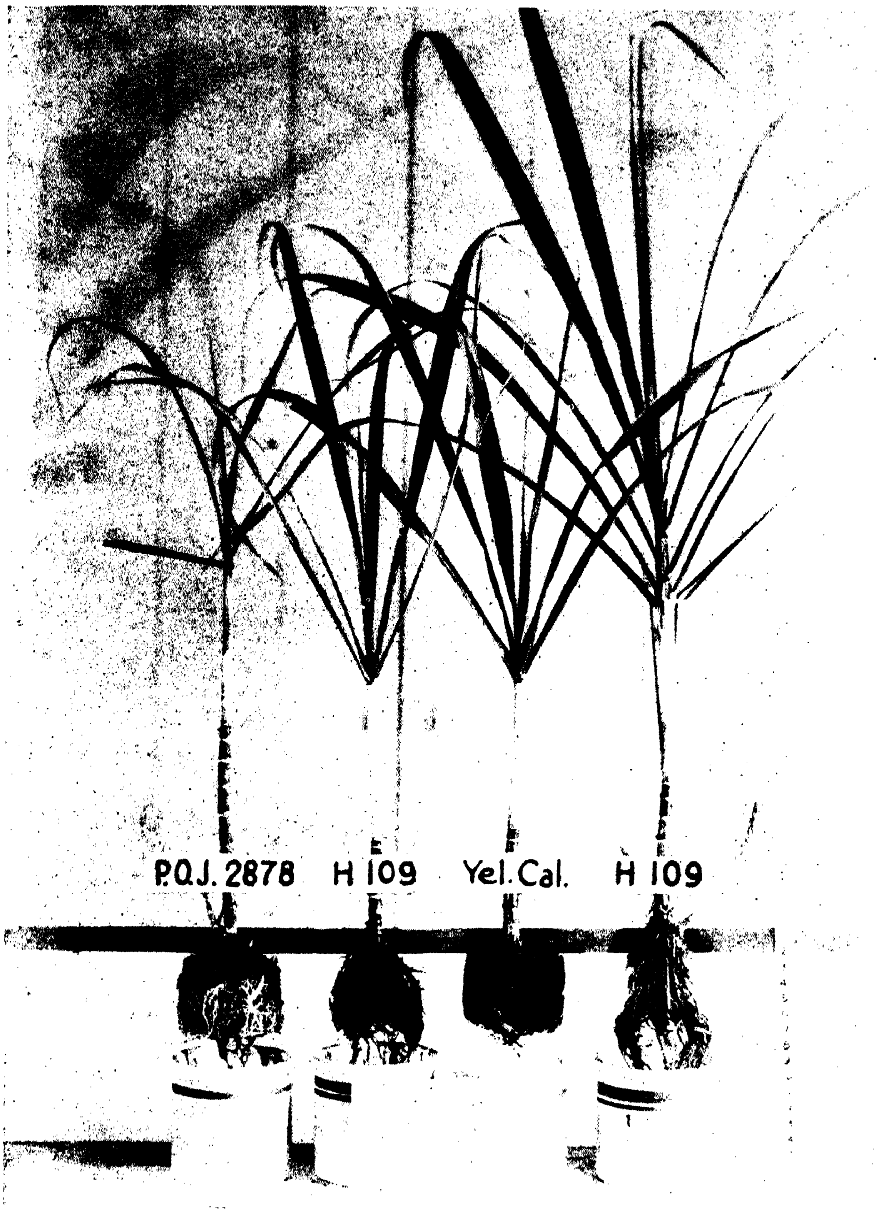


Fig. 8. Minus-phosphorus series, at the end of 216 days. Note the narrow leaves, fan-shaped top, slender stalks, shortened internodes and the tapering of stalks toward the growing point on the three plants on the left. Phosphorus was returned to the H 109 cane plant on the right at the end of 152 days; note the rapid growth response as shown by the elongation and enlargement of the stalk and broad leaf development.

The leaf symptoms of phosphorus deficiency are shown in Plate II and again with the stalk symptoms in Figs. 7 and 8.

The Function of Phosphorus: Phosphorus is an important constituent of proteins but is not required in such large amounts as nitrogen for their formation. Phosphorus occurs in the nucleus, a body, usually spherical, found in living cells, and which is believed to control all the activity that takes place within the cell. Phosphorus is also essential for cell division and for the development of meristematic tissues; it aids in the utilization of certain carbohydrates, particularly starch.

A deficiency of phosphorus interferes with the translocation of carbohydrates within the plant resulting in an accumulation of excess sugars and soluble nitrogen compounds.

Poor bone formation results when cattle are fed on plants deficient in phosphorus. This condition may be corrected by feeding the animals small amounts of bone meal or by applying phosphorus to the soil in which such plants were grown.

Phosphorus is essential during the early life of plants, although the amount required is extremely small when compared with the amounts required of nitrogen, potassium and calcium. It is reported that phosphorus hastens the ripening period of oats and barley if applied shortly before the crops are harvested. It increases tillering of plants and assists in the production of seeds. Large amounts of phosphorus are stored in seeds. It is essential for normal root development and especially so for the development of young roots. In soils low in phosphorus, an abundance of fine or hair-like roots develop, the large roots remaining short and small in diameter.

Sulphur

Deficiency Symptoms: Four to five weeks after sulphur was omitted from the basic solution, the younger leaves of the plants began to lose their normal dark green color. A few weeks later all leaves were of a uniform pale yellowish-green color. The leaf symptoms at this stage were similar to the early leaf symptoms of nitrogen deficiency. As these experiments continued all leaves developed a light lemon-yellow color with a faint purplish tinge on the older leaves. The purplish color became more intense as time went on. Plants deficient in nitrogen did not develop the purple color in the leaves and its presence may be associated with plants deficient in sulphur. The purple color in the leaves is due to the development of anthocyanin, a coloring matter normally found in many species of plants.

The plants in the minus-sulphur series lacked growth and vigor (Figs. 9 and 10), when compared with the control plants. The depressed growth was marked at the end of 6 or 8 weeks. A poor root system developed on the plants and considerable damage resulted from *Pythium* root rot (Fig. 10).

The plants deprived of sulphur and showing definite deficiency symptoms made a quick recovery when sulphur was returned to the nutrient solution (Fig. 10). The plants regained their normal green color and began to make a normal growth. Sulphur-deficiency symptoms on sugar cane are shown in Figs. 9 and 10 and in Plate II.

The Function of Sulphur: Sulphur in combination with carbon, hydrogen, nitrogen and oxygen goes to make proteins which in turn enter largely into the formation of the protoplasm of the plant cells.

A deficiency of sulphur retards the formation of proteins which immediately causes a retardation of plant growth. The leaves gradually lose their dark green color and become chlorotic. This condition indicates an accumulation of carbohydrates in the leaves.

It has been shown that the addition of sulphur to fertilizers has a beneficial effect on plant growth.

MANGANESE

Deficiency Symptoms: In the deficiency series where manganese was omitted, the plants continued to make what appeared to be a normal growth for 2 months (Fig. 11). At the end of this time the first leaf symptoms were observed. On the young leaves, a leaf striping somewhat similar to the early symptoms of iron deficiency appeared. The striping developed more frequently toward the middle and tips of the leaves and seldom continued the full length of the leaves. This characteristic has proved valuable for differentiating the early symptoms of manganese deficiency from those of iron deficiency.

The leaves at first showed alternating dark green and light green stripes, the former being slightly the wider. At the end of 3 months, the light green stripes were almost entirely chlorotic or white and the effect was very marked. As the experiment continued, the dark green stripes became slightly chlorotic, thus making the striping less conspicuous. Small necrotic regions soon appeared in the

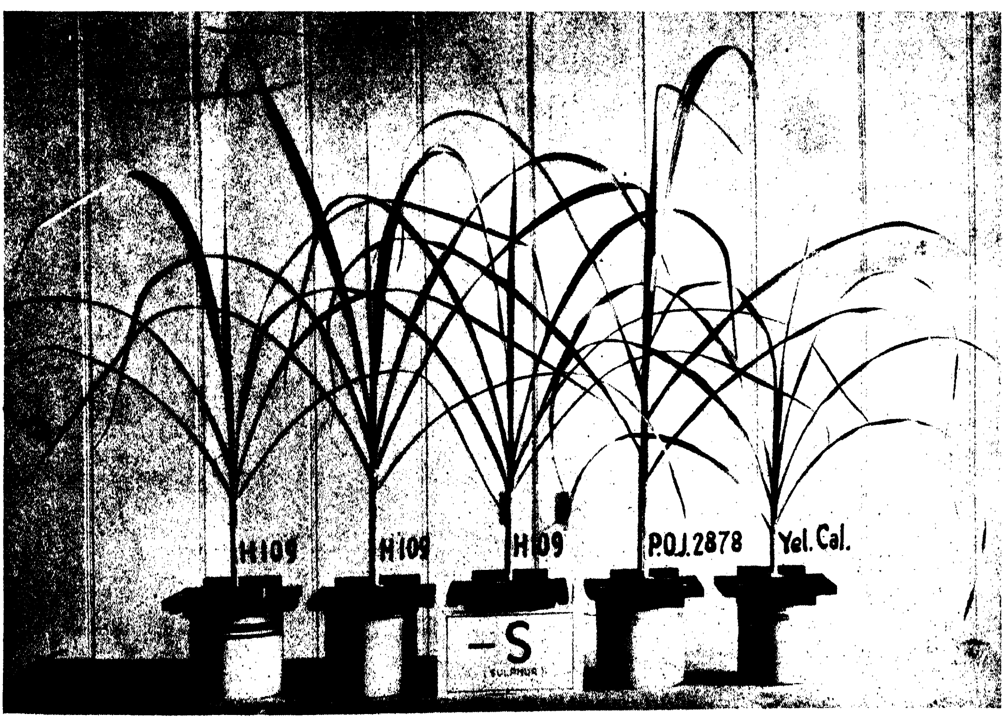


Fig. 9. Minus-sulphur series, at the end of 80 days. The growth of the plants was retarded and definite leaf symptoms of sulphur deficiency were present on the leaves.

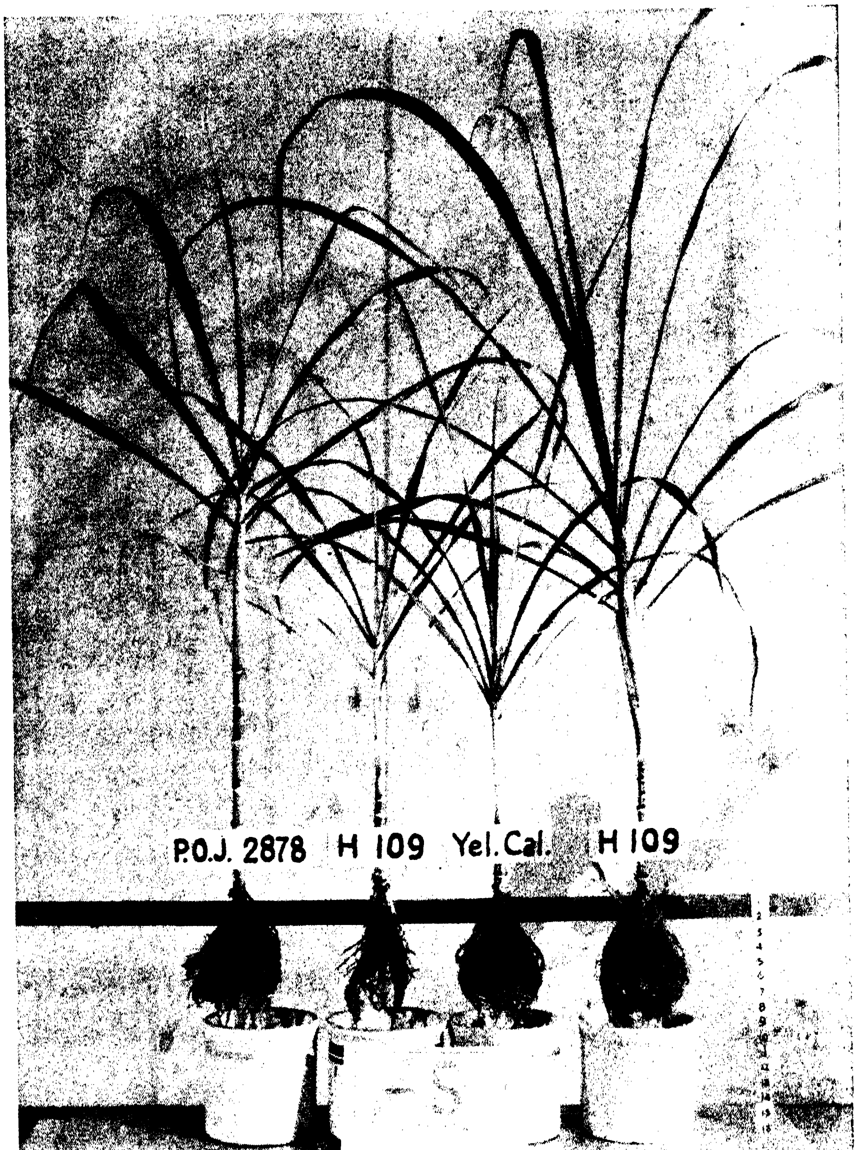
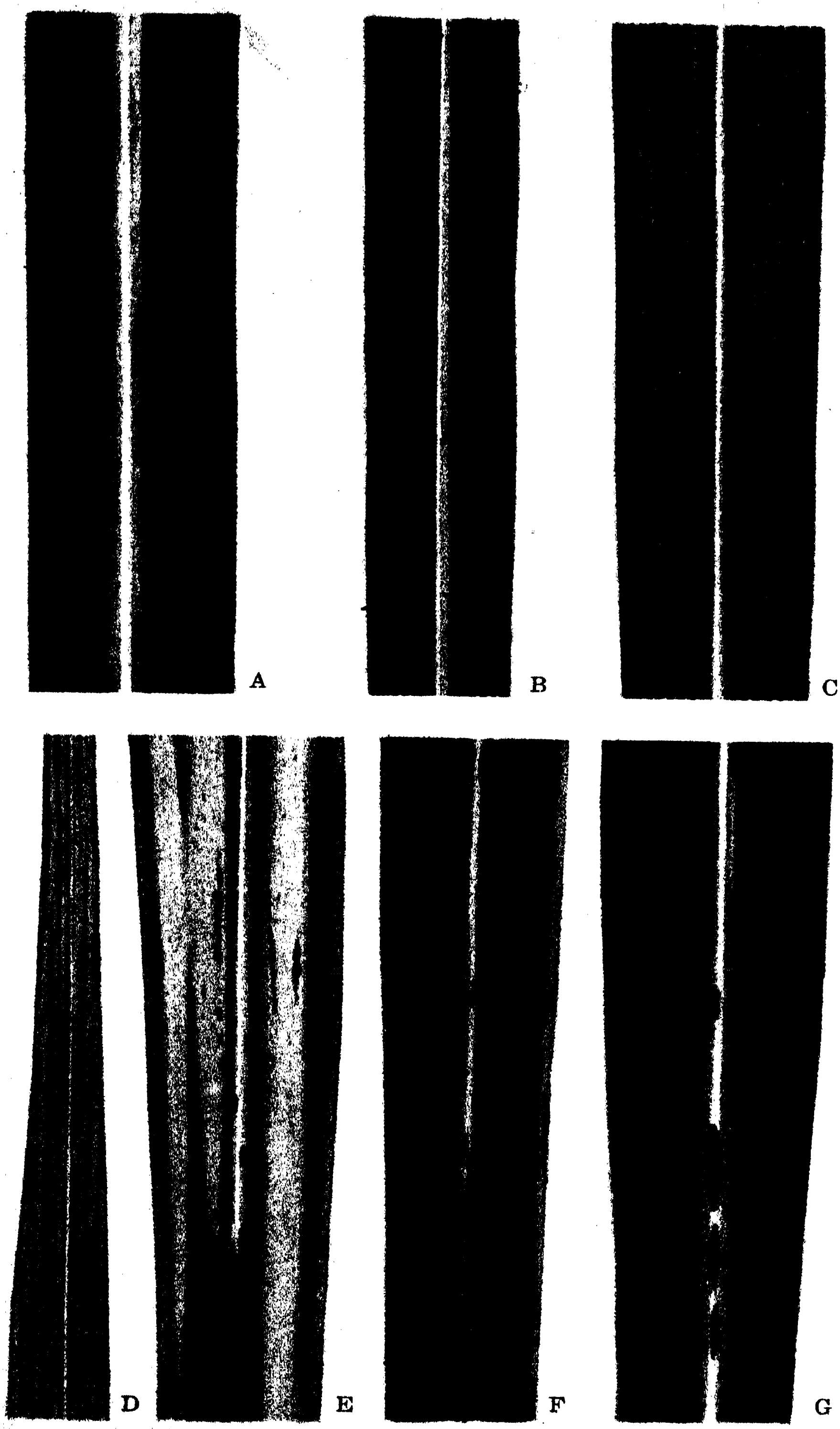


Fig. 10. Minus-sulphur series, at the end of 216 days. Note greatly depressed growth and poor root development especially on the three plants on the left. The leaves on these plants were of a pale yellowish-green color with traces of a purplish tinge on the older leaves. When sulphur was returned to the solution, a normal growth resulted, as shown by the H 109 cane plant on the right.

PLATE III



A—Normal Leaf
B, C—Manganese Deficiency
D, E, F, G—Potassium Deficiency

white stripes; later, these regions coalesced, making continuous stripes of dead, dry tissue, which frequently split or cracked longitudinally. At one time, this nutritional condition was called leaf splitting disease and was attributed to the fungus, *Mycosphaerella striatiformans.* This leaf trouble, the cause of which is a deficiency of manganese, is commonly known as Pahala blight.

Shortly after the leaf symptoms developed, the plants failed to make further growth. The leaf and stalk tissues became soft and "rubbery" in texture. Due to this weakened condition, the leaves began to droop and the youngest leaves began to die. The plants, in an effort to continue their growth, developed side shoots but these were also extremely weak. The root systems were in a weakened condition, *Pythium* root rot was present in abundance (Fig. 12), and the plants soon died.

When manganese was added to the nutrient solution containing the dying plants, normal color developed and growth was resumed, while the leaves which developed were free from any leaf striping (Fig. 12). The addition of manganese to the culture solution which was at the rate of .25 p. p. m. or approximately three-quarters of a pound per acre, clearly demonstrates the necessity of having certain elements present even though the amount sometimes appears to be almost negligible.

Symptoms of Pahala blight occurring on sugar cane in the fields have been described by Cobb (2), Lyon (10), McGeorge (11), and Lee and McHargue (9). The symptoms of Pahala blight, or manganese deficiency, appearing on sugar cane grown in culture solutions have been described by Davis (4) and Martin (12).

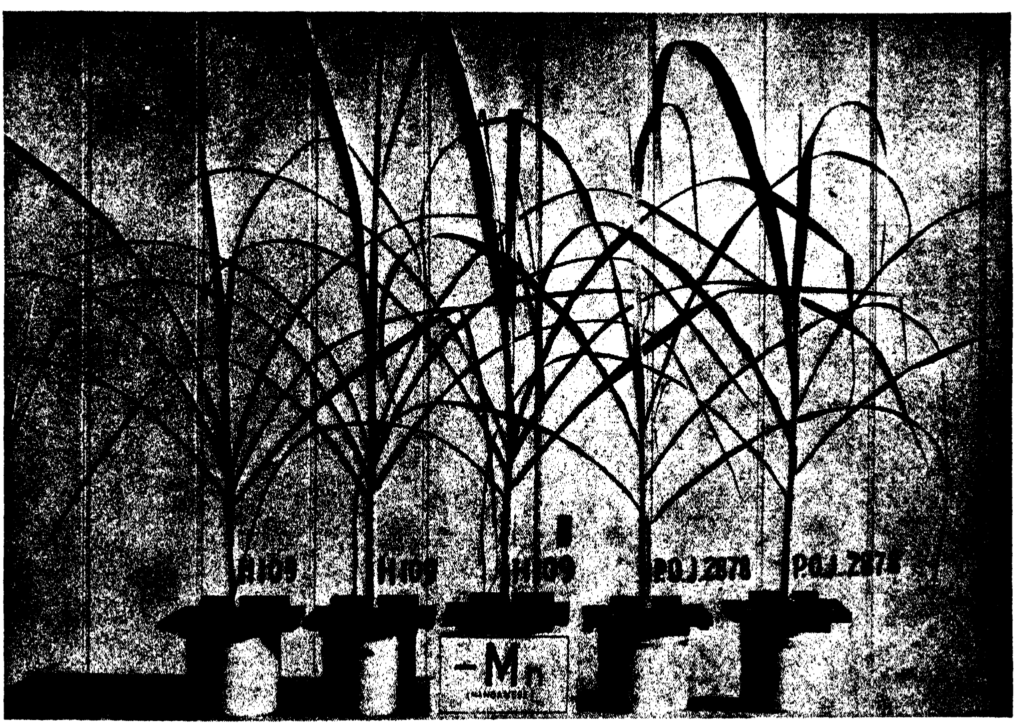


Fig. 11. Minus-manganese series, at the end of 80 days. The growth of the cane plants up to this time was about equal to that of the control plants (Fig. 1), although definite leaf symptoms of manganese deficiency were present.

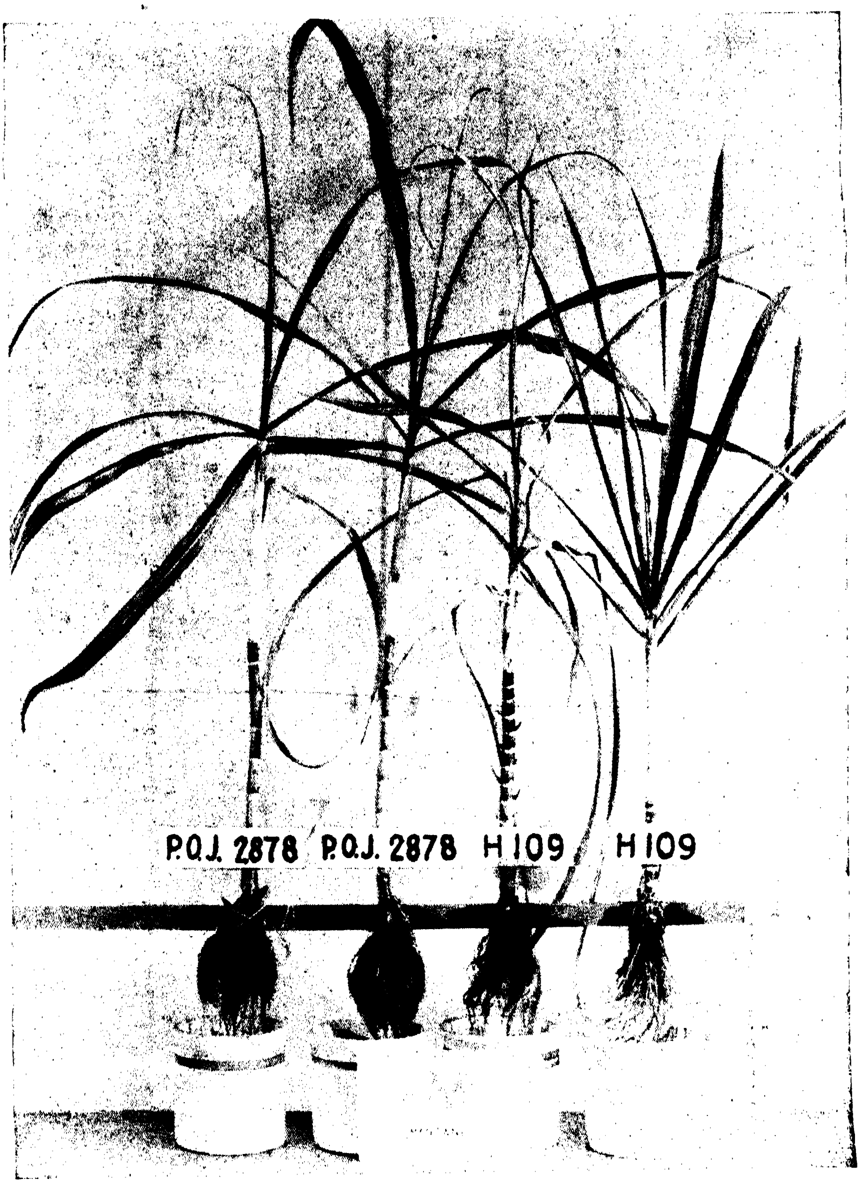


Fig. 12. Minus-manganese series, at the end of 216 days. The three plants on the left failed to make further growth, the leaf and stalk tissues became soft and "rubbery", the leaves began to droop, and the leaf spindles began to die. The leaf striping or symptoms of manganese deficiency were very acute. The roots were poorly developed and greatly weakened by *Pythium* root rot. When manganese was again added to the solution the deficiency symptoms quickly disappeared and the plant made a normal growth, as shown by the H 109 cane plant on the right.

Leaf and stalk symptoms of manganese deficiency are shown in Figs. 11 and 12 and in Plate III.

The Function of Manganese: It has been demonstrated that extremely small quantities of manganese are essential for the growth of certain plants. However, the role that manganese plays in plant metabolism is not clearly understood.

Manganese is said to aid in certain oxidation processes that take place in the plant. It seems to be of special importance to the development of the immature tissues at or near the growing point.

The sugar cane plants in the minus-manganese series were found to have a low activity in oxidase by Dr. C. E. Hartt, who is conducting special studies on the activities of enzymes in the cane plant at this Experiment Station.

Miller (13) states:

> The function performed by Mn in the metabolism of the plant rests almost entirely on theoretical grounds. Bertrand (1897, 1905, and 1912) considered that the addition of small amounts of soluble Mn increases the oxygen-carrying power of the oxidases. This enzyme is universally present in plants and fulfills a definite function in their metabolism . . . . . McHargue (1922) thinks that manganese is concerned in nitrogen assimilation and the synthesis of proteins and that it plays the role of a necessary catalyst in plant metabolism and also functions with iron in the synthesis of chlorophyll.

Potassium

Deficiency Symptoms: The first visible deficiency symptoms exhibited by the plants in the minus-potassium solution was the retardation of growth. At the end of 4 to 6 weeks, the growth of the plants was greatly retarded; the stalks tapered rapidly toward the growing point and the tops assumed a fan-like appearance (Figs. 13 and 14).

The older leaves began to die back from the tips and margins, resulting in a definite firing of the leaf edges. The older leaves also gradually changed from a dark green to a pale yellowish color and on these leaves numerous minute chlorotic spots appeared. These spots later became brown with necrotic centers. The leaf spotting was much more pronounced on the older leaves than on the younger leaves. In advanced cases the leaf spotting was very common, the part affected being the parenchyma, or the tissue that lies between the vascular bundles. The young leaves of plants deficient in potassium developed a darker green than the control plants.

The above symptoms are similar to those described by Naquin (14) in 1926; his description was of plants which were grown under field conditions.

A very definite reddish discoloration appeared on the upper surfaces of the midribs of the older leaves and was most pronounced toward the bases of the leaves. The presence of this midrib discoloration is one of the most definite symptoms for recognizing potassium deficiency in sugar cane plants. The discoloration is due to the development of a red color in the cell wall which is limited almost entirely to the cells near the upper surface of the midrib.

Upon the addition of potassium, the plants in the minus-potassium series rapidly assumed a normal growth (Fig 14). The leaf symptoms quickly disappeared and the color of the plants became normal.

An abnormal root development resulted in this series. The roots were badly attacked with *Pythium* root rot.

Potassium-deficiency symptoms developing on sugar cane in culture solutions have been studied and described by Hartt (5) and van den Honert (16).

Symptoms of potassium deficiency are shown in Figs. 13 and 14 and in Plate III.

The Function of Potassium: Potassium is required by plants in rather large amounts. Almost all of the potassium contained in plant tissues is readily soluble in water and possibly occurs in plant cells in inorganic form. Potassium migrates from the older parts of the plants toward the meristematic, or growing, tissues; this is evidenced by cane plants deficient in this element. The older leaves gradually manifest potassium-deficiency symptoms and if a shortage of potassium continues, the symptoms become extremely pronounced on the older leaves and begin to develop on the younger leaves. The youngest leaves are the last to manifest the symptoms which may be explained by the movement of potassium within the plant from the older to the younger leaves.

It is thought that potassium aids in carbon assimilation, translocation of sugars, and in starch formation. Potassium is essential for the general processes of cell division, although its specific role in this connection is not clear. Sweet potatoes and sugar beets deficient in potassium become elongated and small in diameter.

There is considerable evidence that a deficiency of potassium interferes with the formation of proteins, the formation and digestion of carbohydrates, and probably with the translocation of these materials.

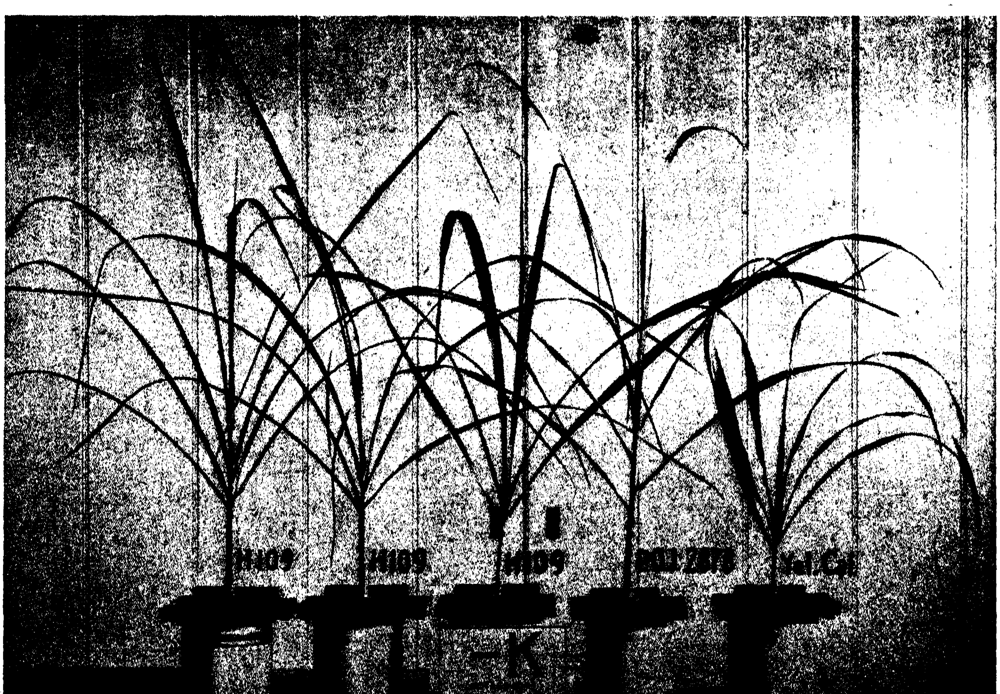


Fig. 13. Minus-potassium series, at the end of 80 days. The growth of the plants was depressed and definite leaf symptoms of potassium deficiency were present.

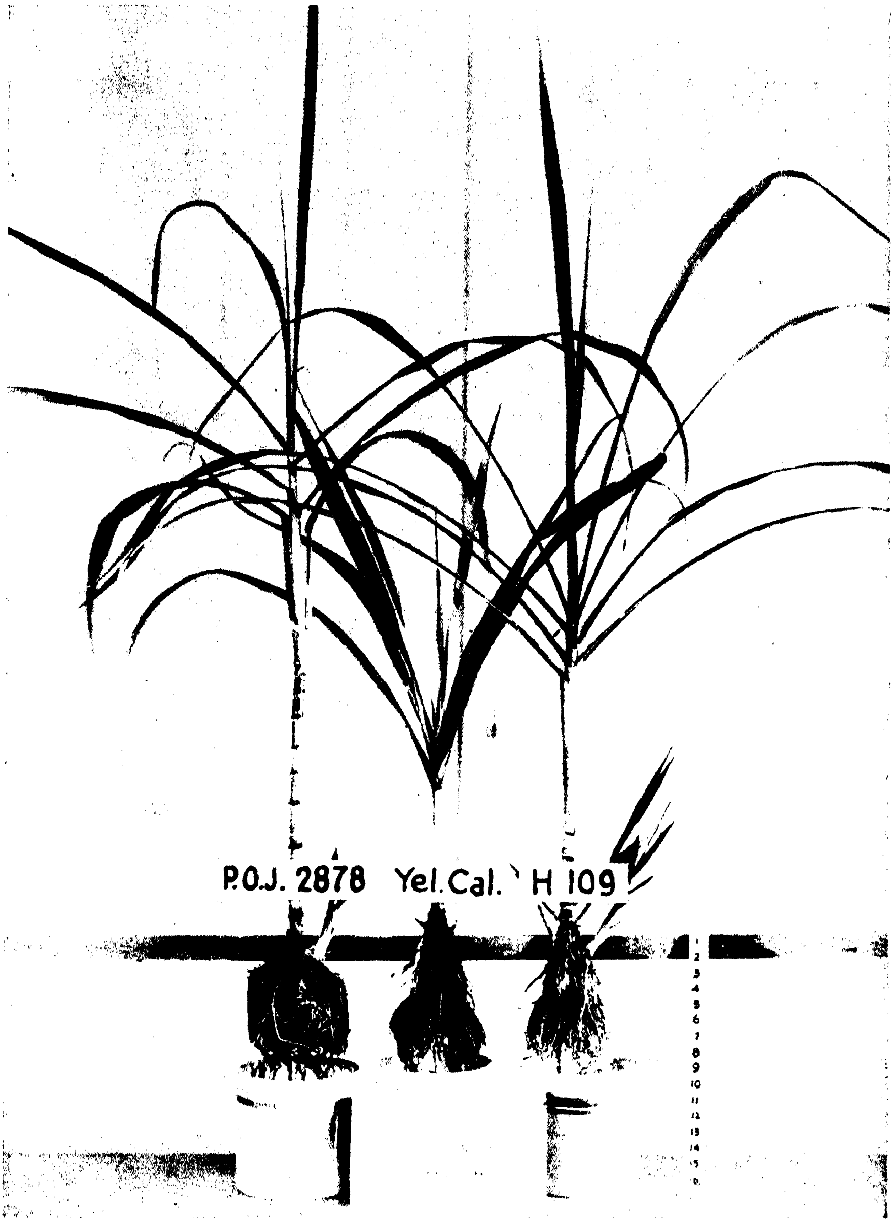


Fig. 14. Minus-potassium series, at the end of 216 days. Growth was greatly retarded, the stalks were small in diameter and definite leaf symptoms of potassium deficiency appeared on the plants. At the end of 152 days, potassium was again added to the solution in which the H 109 plant on the right had been growing; a normal growth resulted and the deficiency leaf symptoms disappeared.

Under some conditions, potassium salts apparently facilitate the entry of water into the plant. An adequate supply of potassium is essential for normal root development. An inadequate supply results in the development of primary roots that are abnormally fine and which develop few secondary roots.

Dr. Hartt, who has contributed extensively to a better understanding of the physiological role of potassium in the sugar cane plant, summarizes her studies to date as follows:

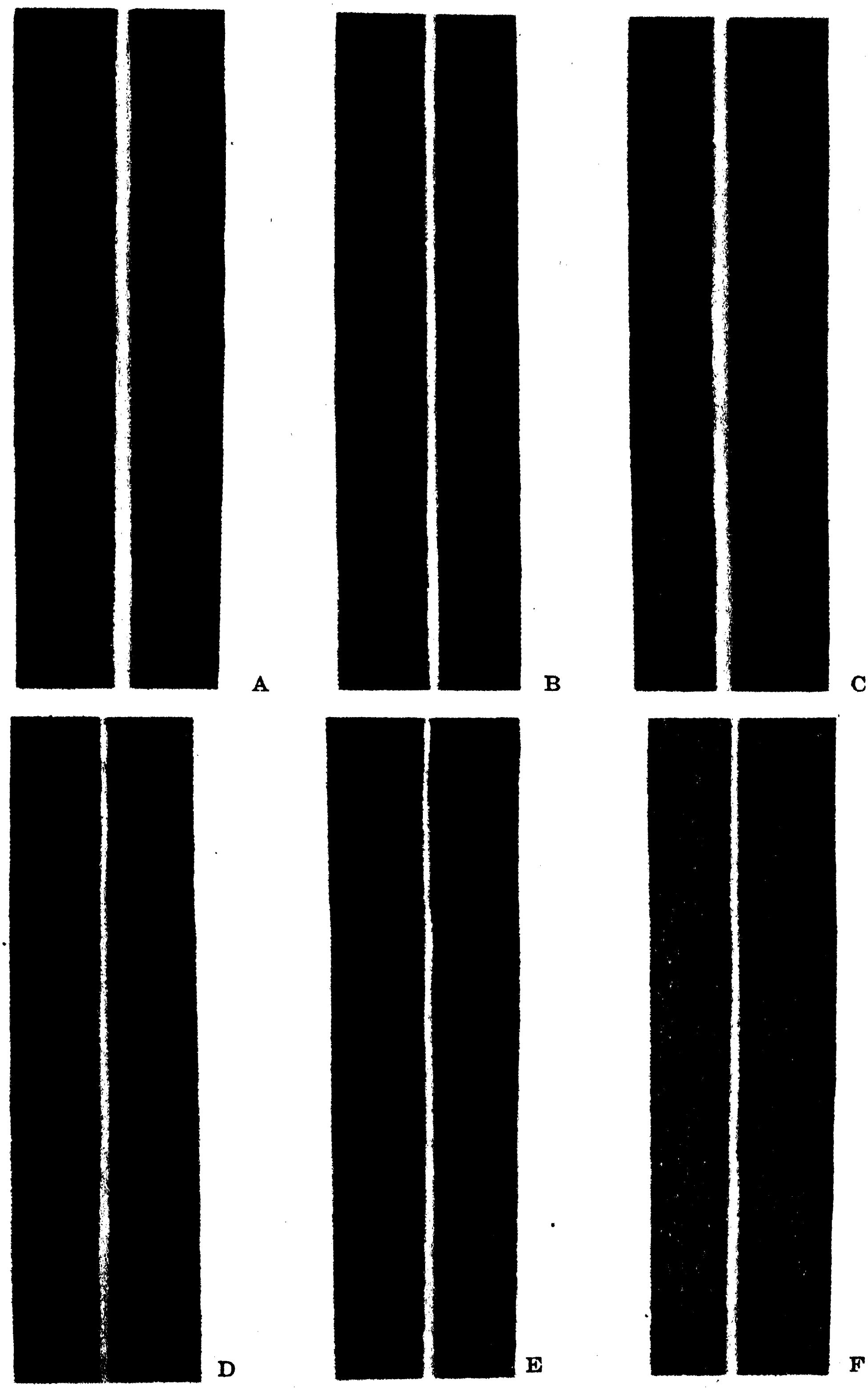
> The symptoms of potassium deficiency in sugar cane were found to be decreased growth (5, 7), "dieback" and discoloration of the leaves. The development of red midribs in plants deficient in potassium was associated with an excess of sulphates or possibly chlorides (7).
>
> In 1929 (5), a report was made of the results of quantitative determinations of the activity of diastase, invertase, peptase, ereptase and catalase. The effect of potassium upon enzyme activity was found to vary with the kind of enzyme, the species, age and organ of the plant studied. The potassium-deficient plants had greatest diastase activity in all parts except the roots, in which activity was equal in all the plants. The invertase activity in the blades was greater in the controls than in the potassium-deficient plants. Peptase and catalase activities were greatest in the plants supplied with potassium. Ereptase activity was the same in all the plants. Differences were also found in moisture, sugars, lignification and cutinization. Greater lignification and higher percentages of sugars were found associated with a weak activity of peptase in the plants deficient in potassium, suggesting the conclusion that an upset in the synthesis of proteins may lead to the accumulation of carbohydrates, a conclusion reached by Nightingale et al. (15) in 1930, who found the accumulations of carbohydrates to be an early response in potassium deficiency, disappearing later.
>
> In a later study, the effects of potassium upon the growth of sugar cane and upon the absorption and migrations of ash constituents (7), as well as upon the amounts of protein and amino forms of nitrogen, sugars and enzyme activity are reported (8). Higher percentages of reducing sugars and lower percentages of sucrose were found associated with weaker activity of invertase in the blades of the plants deficient in potassium (8). The plants deficient in potassium developed the following characteristics: low percentages of moisture; high total ash content when young, followed later by low ash percentage, high percentages of calcium, magnesium, phosphorus and iron at certain ages, derangements in the synthesis and translocation of proteins and sugars; phloem necrosis, accumulation of iron at the nodes; weak activity of invertase and strong amylase activity. Migration of potassium from the lower dying leaves to the living tops occurred in all the series and was not associated with a deficiency in potassium.

MAGNESIUM

Deficiency Symptoms: A reduction in growth of the cane plants in the minus-magnesium series was noted at the end of 4 weeks. The stalks became slender and the older leaves manifested a chlorotic condition (Fig. 15). The young leaves lost some of their dark green color but not to the extent of the more mature ones.

Within 4 to 6 weeks, minute chlorotic spots began to appear on the older leaves. Later these spots turned to a dark brown color and were uniformly distributed over the surface of the leaves. The minute spots or lesions were extremely common and frequently coalesced, thus giving a "rusty" appearance to the leaves. The spotting was most pronounced on the older leaves and decreased in severity on the younger leaves.

PLATE IV



A, B, C—Magnesium Deficiency
D, E, F—Calcium Deficiency

The growth of the plants at the end of 216 days (Fig. 16) was greatly reduced when compared with the growth of the control plants. In this series, P. O. J. 2878 produced the greatest amount of growth while Yellow Caledonia produced the least. It is interesting to note that P. O. J. 2878 made more growth than the other two varieties in practically every deficiency series.

When plants deficient in magnesium were transferred to a solution containing magnesium, the new growth produced was normal and the chlorotic leaves regained their normal green color (Fig. 16). No further leaf spotting developed.

Symptoms of magnesium deficiency are shown in Figs. 15 and 16 and in Plate IV.

The Function of Magnesium: Magnesium is one of the constituents of the chlorophyll molecule and a deficiency of this element in a plant would naturally reduce or prevent the formation of chlorophyll. A shortage of magnesium would, therefore, result in a chlorotic condition of the leaves or green parts of the plant.

Magnesium, according to some investigators, aids in the translocation of phosphorus, particularly from the older to the more rapidly growing parts of the plant.

It has also been pointed out that magnesium is essential for the formation and utilization of oils in plants. Seeds having high oil content contain much more magnesium than those having a high starch content.

An excess of magnesium may prove toxic to plant growth and is sometimes corrected by the addition of calcium to the soil, usually in the form of agricultural lime. Considerable experimental work has been carried out in relation to the calcium-magnesium ratio in plants as well as in the soil.

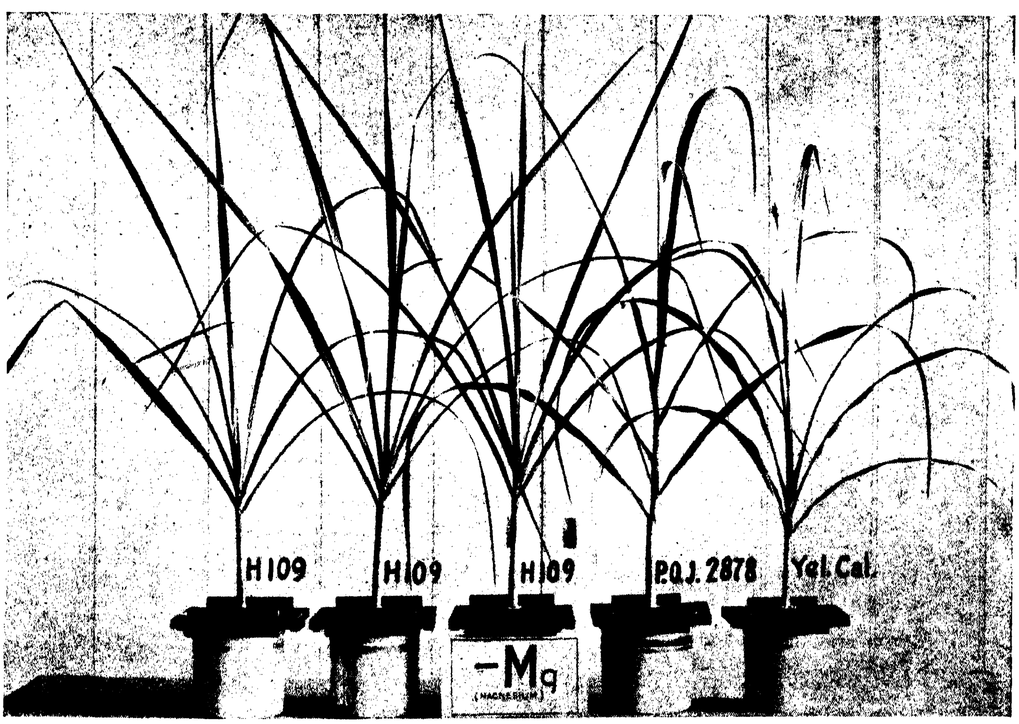


Fig. 15. Minus-magnesium series, at the end of 80 days. The growth of the plants was slightly less than the growth of the control plants (Fig. 1). Very definite leaf symptoms of magnesium deficiency appeared on these plants.

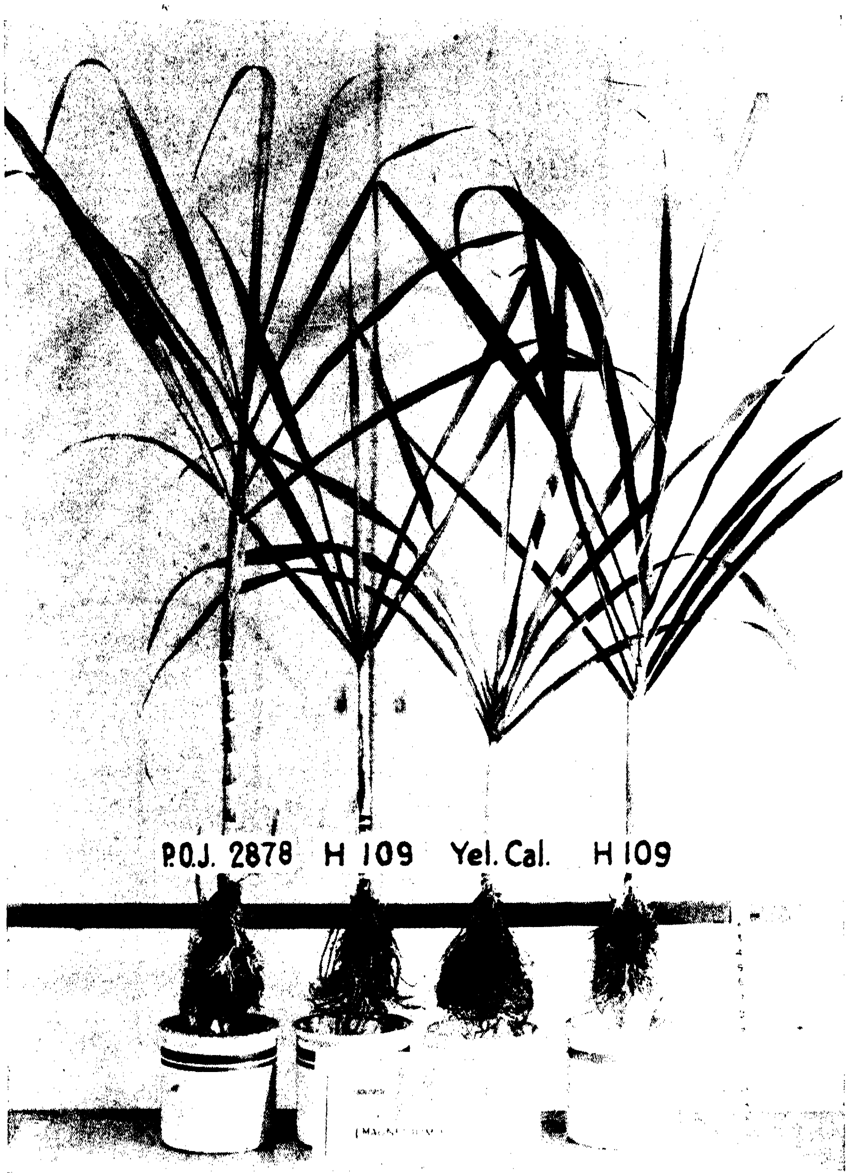


Fig. 16. Minus-magnesium series, at the end of 216 days. Cane growth was greatly retarded in contrast with the control plants (Fig. 2). The leaf spotting or leaf symptoms were very pronounced on the older leaves. Considerable root injury resulted from *Pythium* root rot. Upon the return of magnesium to the H 109 cane plant on the right, normal growth resulted; no further leaf symptoms appeared.

CALCIUM

Deficiency Symptoms: In the various deficiency series, the greatest injury to the plants occurred in the minus-calcium solution.

Within 3 to 4 weeks, a slight chlorotic condition of the leaves as well as a marked retardation of growth resulted (Fig. 17). Minute spots, giving a peppered appearance, also began to develop on the older leaves. These spots were extremely numerous and later became dark reddish-brown in color with dead centers. The necrotic areas soon coalesced and almost the entire leaf was involved. In such cases, the leaves quickly died. The injury from the spotting increased with the age of the leaves; however, severe injury occurred on comparatively young leaves. The spots resembled those in the minus-potassium series and the minus-magnesium series.

The innermost or youngest leaves became extremely weak and failed to make further growth. This condition was followed by the death of the spindle, the growing point of each plant, and, in a few cases the entire plant (Fig. 18).

The effect on the root growth was very marked. Root development was greatly retarded in 2 to 3 weeks after calcium had been omitted from the nutrient solution. The roots became soft and flaccid as a result of *Pythium* root rot. At the end of 8 to 10 weeks, the rot was so severe that practically every root had died. The greatest damage from *Pythium* root rot occurred in this series.

When the rapidly dying plants were placed in a plus-calcium solution, an immediate growth response resulted (Fig. 18). Since the terminal bud had died on

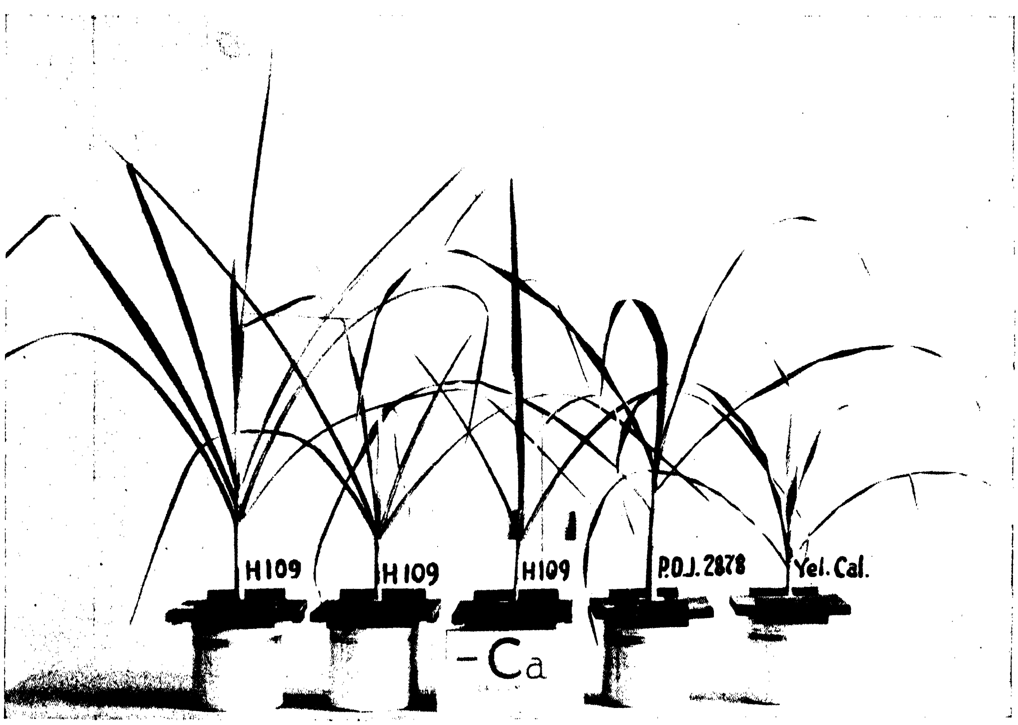


Fig. 17. Minus-calcium series, at the end of 80 days. The growth of these plants was greatly depressed when compared with that of the control plants (Fig. 1). The leaf symptoms of calcium deficiency were very pronounced. Severe root injury from *Pythium* root rot occurred on these plants. The plants in general were in a very weakened condition.

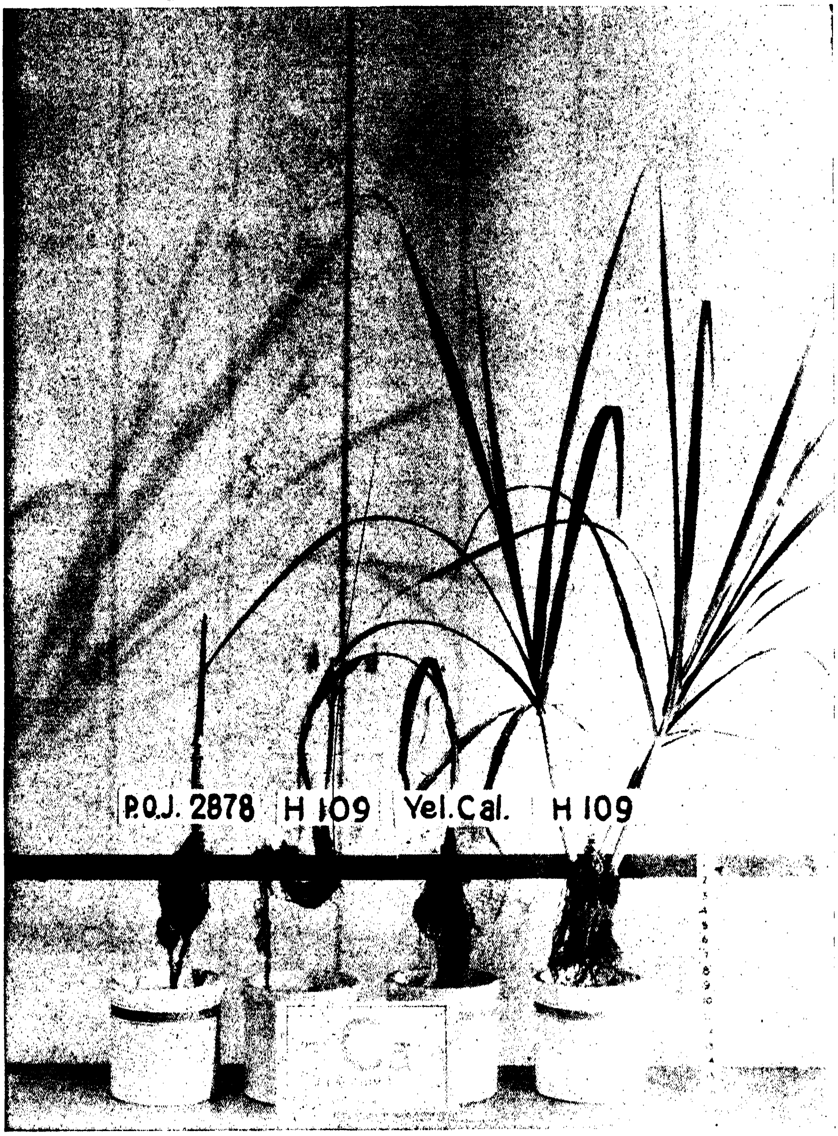


Fig. 18. Minus-calcium series, at the end of 216 days. The three plants on the left have died. These plants made little or no growth after calcium was removed from the solution. The roots were severely injured by *Pythium* root rot. Calcium was returned to the H 109 cane plant on the right at the end of 152 days. The growing point had already died but a rapid growth developed from the lateral buds. The new growth was normal in every respect.

each plant in the minus-calcium solution, the lateral or side buds began to develop shoots of a normal color and growth.

Leaf and stalk symptoms of calcium deficiency are shown in Figs. 17 and 18 and in Plate IV.

The Function of Calcium: Calcium is regarded by some as the key element in relation to the absorption of the other elements. A nutrient solution minus calcium is no better for plant growth than distilled water.

With a good supply of calcium, the cell wall constituents are rendered more firm, due to the formation of calcium pectate, which is the cementing substance that holds the cells together. Between the cells is found the middle lamella, which is composed of calcium pectate.

It is thought that certain calcium salts form a precipitate which constitutes a semi-permeable membrane, and that this membrane offers protection to the protoplasm by preventing the contact of toxic elements with the protoplasm. Calcium is considered an antitoxic agent in that it prevents injury to the protoplasm of the cell that certain ions might produce. For instance, magnesium in high concentrations is toxic to plant growth but with the addition of calcium, the same concentration of magnesium is rendered non-toxic. Gypsum, or calcium sulphate, is frequently applied to alkali soils to counteract the harmful effect from excesses of magnesium or sodium.

With a calcium deficiency, an over-accumulation of carbohydrates occurs and a disintegration of phloem takes place and, in the case of the latter, the translocation of foods is delayed which often results in an accumulation of starch in the leaves.

Calcium is essential for normal root development. With a deficiency of this element the roots are greatly weakened and are subject to attack by parasitic organisms. This was specially true in relation to the root development of sugar cane plants which were grown in a minus-calcium solution. The roots were severely affected by *Pythium* root rot.

IV. Discussion

The quantity and availability of the essential elements for plant growth occurring in the soil or culture solutions govern, to a large extent, the amount of any one element found in the plant. It is possible to change the chemical composition of the plant by altering the medium in which it is grown.

A chemical analysis of plants grown in a nutrient solution, from which an element has been omitted, shows that the proportionate amounts of the various elements present in these plants differ from the amounts of the same elements in plants grown in a complete nutrient solution. This was found to be true in more recent studies in which chemical analyses were made of sugar cane plants grown in solutions deficient in each of the eight elements referred to in this paper. The effects on growth, when any one element was omitted, may have been because, (1) the element was essential for certain metabolic processes within the plant, or (2) the rate of absorption of the various elements was affected by the antagonism which resulted among the elements in the "unbalanced" solution. In either case

the effects on the plants were characteristic for each element omitted, thus making it possible to distinguish *deficiency symptoms* of one element from another.

It required much more time for the deficiency symptoms to develop on the plants after they were placed in the incomplete solutions than it did for the plants to manifest a recovery when the element was again added to the medium. The plants, no doubt, absorbed the elements in excess of their requirements before they were transferred to the deficiency series and manifested an abnormal growth only after the reserve of the element was exhausted within the plant in each deficiency series.

Of the three cane varieties, Yellow Caledonia was, without exception, the first to manifest the deficiency symptoms, while H 109 and P. O. J. 2878 were next in order. In each deficiency series, the growth of P. O. J. 2878 was much superior to the other two varieties. Possibly, the culture solution was more favorable for the growth of P. O. J. 2878, or that smaller quantities of the elements were required for its development, or that P. O. J. 2878 built up a greater reserve of all elements than the other varieties at the beginning of the experiment.

V. Summary

1. A nutrient solution, containing the elements essential for plant growth, was found to be favorable for normal growth of the sugar cane plant. Methods for growing sugar cane plants in water cultures are described.
2. When nitrogen, iron, phosphorus, sulphur, manganese, potassium, magnesium or calcium was omitted from the complete nutrient solution, an abnormal growth of sugar cane plants resulted.
3. A reduction in cane growth occurred in each deficiency series, i. e., when any one of the eight elements was omitted from the solution.
4. Definite leaf, stalk or root symptoms developed on plants in each deficiency series. Deficiency symptoms of each element are described and illustrated.
5. The deficiency symptoms which proved to be typical for each element may serve to distinguish similar deficiency symptoms should they appear on sugar cane when grown under field conditions.

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Notes on New Varieties

28-1234 (P.O.J. 2364 x 26 C 270).

A three-replication test comparing 28-1234 with H 109 was harvested recently at Waianae Company by F. C. Denison in cooperation with the plantation. In view of the widespread interest in this seedling it may be in order to report the results in detail.

The experiment was planted on March 5, 1932, and harvested on April 7, 1934, at 25 months of age. It was situated in Field 28, a low-lying, level field, with a fertile loamy soil. The plots were of watercourse size, one-sixth to one-tenth acre each, with check plots of H 109 adjoining. The yield data are given below:

	No. of Plots	TC/A	Q. R.	Yield % Cane	TS/A	TS/A Gain
28-1234	3	129.9	9.08	11.01	14.3	3.0
H 109	5	98.5	8.85	11.50	11.3	

It was obvious as the cane lay on the ground at harvest that the 28-1234 had made a heavier tonnage than H 109. However, considerably more dead cane could be seen in the 28-1234 than in the H 109 plots. It appeared that 28-1234 had passed its prime and that it would have performed to still better advantage had the test been harvested a few months earlier.*

It is a matter of considerable interest that 28-1234 should have defeated H 109 under conditions particularly suited to the latter variety. We believe, however, that this seedling will prove most useful under less fertile conditions where H 109 fails to produce satisfactory tonnages.

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* It should be mentioned that 28-2014, a sister of 28-1234, also did remarkably well in this test, outyielding even 28-1234 by a small margin.

Another bit of evidence in support of 28-1234 has recently come from the Hamakua Variety Station, the conditions of which are quite the opposite of those which prevailed in the Waianae experiment reported above. The Hamakua Variety Station is situated at an elevation of 1,100 feet, and the seedlings in this Field Trial 2 planting have had to contend with two periods of extreme drought. Under these adverse conditions 28-1234 stood at the head of the list of some 40 seedlings, outyielding P.O.J. 36 by over four tons of sugar per acre. The juices of 28-1234 were slightly better than those of the P.O.J. 36 check plots.

The versatility of 28-1234 is such that it may be recommended for trial under all conditions except in localities where eye-spot disease is severe. While not as susceptible as H 109, it has nevertheless been badly affected in areas particularly favorable to the development of the disease.

31-1389 (P.O.J. 2878 x 26 C 270).

This seedling is closely related to 28-1234, as shown by the above parentage.

Reports from tests of 31-1389 under makai conditions point to it as the strongest competitor of H 109 and P.O.J. 2878 now in the field. It is highly resistant to eye-spot disease and can be used to replace H 109 under conditions of severe eye-spot with full assurance of improved yields. Preliminary juice tests have been equal to or better than those of the check varieties.

At Waipio Substation this seedling has been consistently ahead of H 109 in all plantings. At Kailua Substation it is superior to P.O.J. 2878. On the plantations it is doing particularly well in preliminary tests at Lihue, Grove Farm, Kekaha, Honolulu Plantation, Ewa, Waialua, Waimanalo, and Maui Agricultural Company.

31-1389 is characterized in all districts by a freckling on the older leaves. This freckling apparently has little effect on the growth of the cane.

Whether 31-1389 will succeed under mauka conditions is questionable. In weedy situations it is likely to prove too open. Under good makai conditions, however, it is unquestionably one of the best of the long list of seedlings now under trial on the plantations. It deserves rapid spreading and thorough testing in all fields where H 109 and P.O.J. 2878 are now being grown.

A. J. M.

The Sugar Cane Plant

A STUDY OF MILLABLE CANE AND SUCROSE FORMATION*

By U. K. Das

Contents

* A progress report of this work has already appeared in *The Hawaiian Planters' Record*, Vol. XXXVI, pp. 399-422, 1932. Some data and discussion contained in that report are here included for the sake of completeness.

I. Introduction

In spite of the excellent agricultural control of our plantations in Hawaii, the cane yield and the juice quality vary tremendously from year to year on the same plantation. Several years ago the writer undertook a series of weather studies in an effort to determine how much of these annual fluctuations could be due to variations in the weather conditions, particularly temperature and rainfall. Mild though these weather variations be in Hawaii compared with many other cane-growing regions, they were, nevertheless, found to exert great influence on our yields, especially cane yields. However, after due allowance was made for changes in cultural policy and the fluctuations in weather conditions, we were still left with unaccountable variations which were particularly large in the case of juice quality. It seemed desirable, therefore, that preparatory to a full understanding of the yield and quality of a cane crop all the factors bearing upon the problem be studied in a systematic manner. The present investigation forms the first part of that broad project.

As we all know, a cane crop is propagated vegetatively by planting seedpieces in the ground. Under favorable conditions of heat and moisture a dormant eye on these seedpieces germinates giving rise to a stalk of cane. In a similar manner this first stalk may later give rise to one or more daughter stalks and these latter may, in course of time, produce granddaughter stalks. At the time of harvest, which in Hawaii is usually 18 to 20 months after planting, the crop may consist of stalks of various ages and consequently in various stages of vigor and maturity. As a first step to a better understanding of our crops, we must therefore know just what a cane crop is, and determine how and to what extent these component parts of a crop affect its average yield and quality.

II. Plan of the Experiment

A uniform area of land at the Experiment Station in Honolulu was divided into eight sections, each section containing 10 lines, each line 35 feet long and 5 feet wide (Fig. 1). Four sections were planted in March and four in September, so that the variations induced by the season of planting could also be studied.

Variety of cane: H 109, which produces roughly 60 per cent of the total yield of Hawaiian sugar plantations.

Seed: Both body and top seed—three-eye pieces.

Fertilization: Uniform in both seasons of planting. Fertilizers were distributed as follows:

At the time of planting 50 lbs. N per acre from ammonium sulphate.
200 lbs. P_2O_5 per acre from superphosphate.
200 lbs. K_2O per acre from potassium sulphate.

At 3 months 50 lbs. N per acre from ammonium sulphate.
At 6 months 75 lbs. N per acre from ammonium sulphate.
At 12 months 50 lbs. N per acre from ammonium sulphate.

Total application: 225 lbs. N per acre.
200 lbs. P_2O_5 per acre.
200 lbs. K_2O per acre.

These amounts are considered to be optimum for average H 109 conditions.

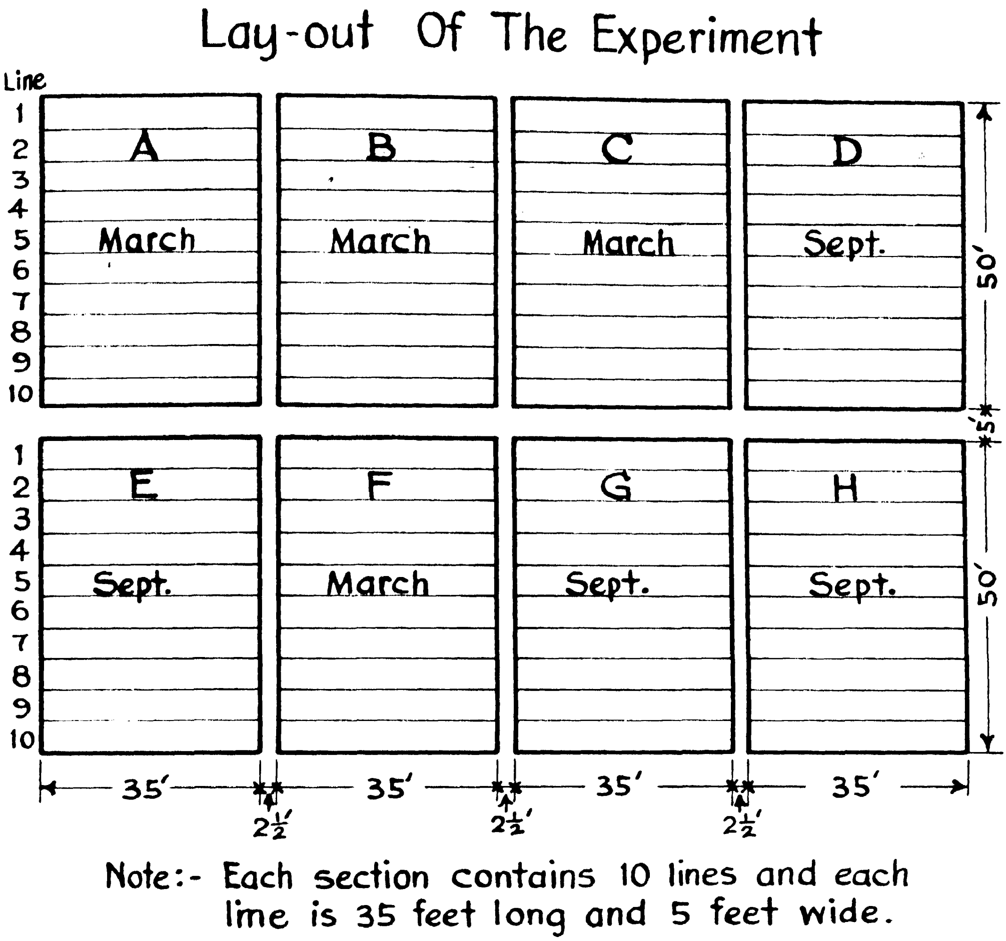
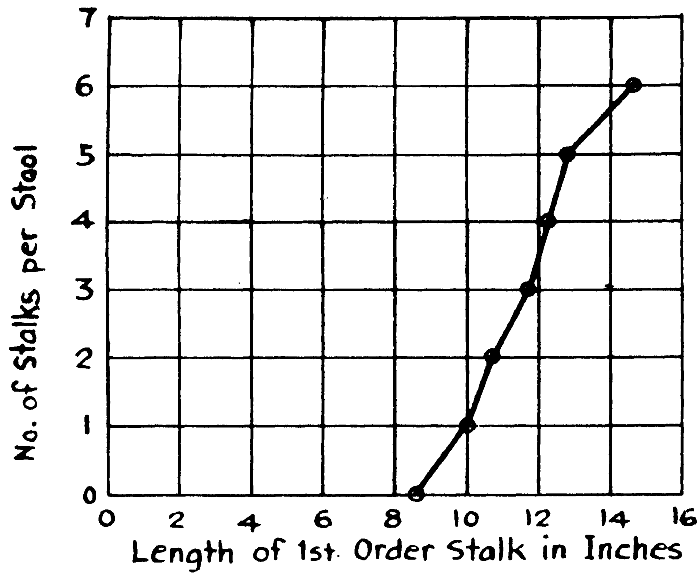


Fig. 1.

Irrigation: Two inches per application, two applications a week. Allowance was made for heavy showers only. Sixteen inches of water applied thus every month is considered to be ample in the irrigated districts of this Territory. The plots were irrigated right to the day of harvest—no attempt being made to influence juice quality by withholding water for a certain length of time before harvest.

On March 17, and September 17, 35 uniform three-eye seedpiecees were planted in each line containing 3 x 35, or 105 potential stalks. After the germination was completed, which took about four weeks, the rows were thinned keeping only 35 more or less uniform stalks to the line. This thinning was undertaken in order to insure a uniform stand of cane in each line. These original shoots which sprung from the seedpieces are herein called mother stalks, primary stalks, or stalks of the first order. Each of these first-order stalks then formed the nucleus of a stool of cane, which consisted of the mother stalk and all the other stalks that arose directly or indirectly from the mother stalks. We then had 35 stools or one stool to a running foot of row in each line.

The first-order stalks were tagged, each tag bearing a number denoting its serial position in the row. Thereafter, at intervals of about two months, the field



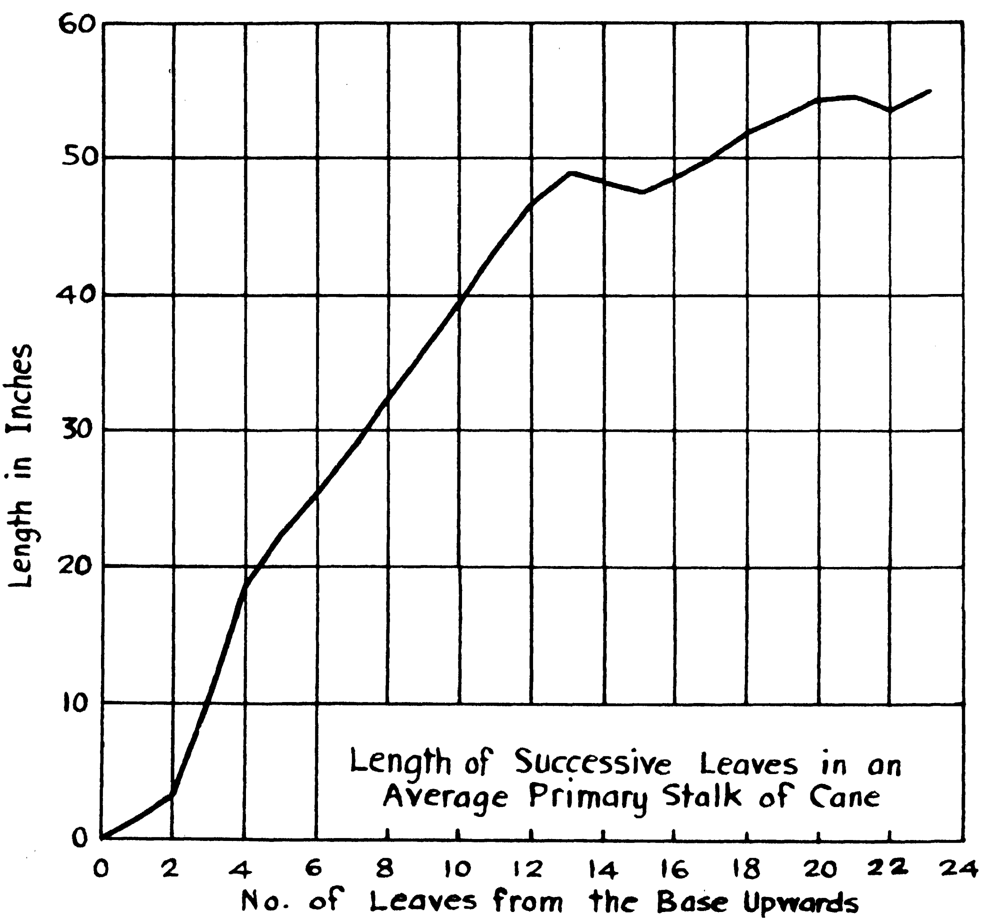


Fig. 2 (above). Showing that at 2½ months of age, the number of shoots per stool is closely related to the size of the primary or first-order stalk. Vigorous primary stalks would therefore insure a good and early stand of cane.

Fig. 2-A (below). As the shoot germinates, the first leaf is very small. Thereafter each successive leaf increases rapidly in length reaching approximately normal length for H 109 around the twenty-fifth leaf. The curve shows three well defined slopes between the first and the twenty-third leaf, the slope flattens out in adult cane, the length remaining more or less constant thereafter as long as the plant is in good vegetative condition.

was carefully gone through and all the shoots that had germinated since our previous tagging were marked with a different kind of tag and these newcomers were successively called the second, third, or higher-order stalks. Order in this paper, therefore, *refers to time of germination* only and not to any morphological relationship of one shoot to another.

III. Suckering—Variations and Seasonal Influences

Individual differences or variations appear to be the most characteristic feature of a growing crop of cane. Starting with selected and uniform seeds and thinning the stand of cane for uniformity, we still find at the age of about 10 weeks that there are great variations in suckering from stool to stool. The number of second-order stalks per stool varies from six to none at all. The first-order stalks show differences among themselves in the matter of size of stalks, number of leaves, and size of leaves.

The number of second-order stalks at this age appears to be correlated to the size of the first-order stalk. The larger the latter, the more numerous the former, as Table I and Fig. 2 will show. This would mean that the rapidity of growth of the first order has an important bearing on the early establishment of a close, thick stand of cane.

Next to this variation in the number of stalks from stool to stool we have the variation in the total number of stalks per line at different ages. Beginning at the age of four weeks we counted the total number of stalks per line at intervals of time. Every care was taken to disturb the cane as little as possible and otherwise keep the conditions approximating field conditions. The results are shown in Table II and Fig. 3.

March planting: Lines 1, 2, and 3 in Sections A, B, C, and F were selected for shoot counts. The total number of lines were 12 representing 420 running feet of row or 420 stools of cane.

We see that at about one month of age this plant field of H 109 has only 35 stalks per line, i.e., there are no suckers.* From then on the number of shoots per line increases to a maximum at about 4½ months of age. This maximum occurs in the early part of August and is followed by a sharp decline continuing through the fall and winter months. There is a little increase in number in the spring of the second year but later harvesting data have shown that this slight increase was offset by the death of older stalks.

Fig. 3 shows only the net results but fails to bring out that in a growing field of cane suckering is a continuous process. Some new suckers are always coming up and others dying, so the population is never exactly the same, though the total number may remain constant.

In the outside line the progress of suckering is quite different from that in the two inside lines. The outside line rises to a greater maximum and the total number does not fall to the level of the two inside lines. Later on we will show that this is due to more space and greater exposure to light obtained by the outside rows.

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* In all the following discussion it must be kept in mind that in this experiment the original stand was thinned to contain only one primary stalk per running foot. The picture might have been different with closer or wider planting.

Number of Stalks per Line on Different Dates - Sec. A, B, C & F

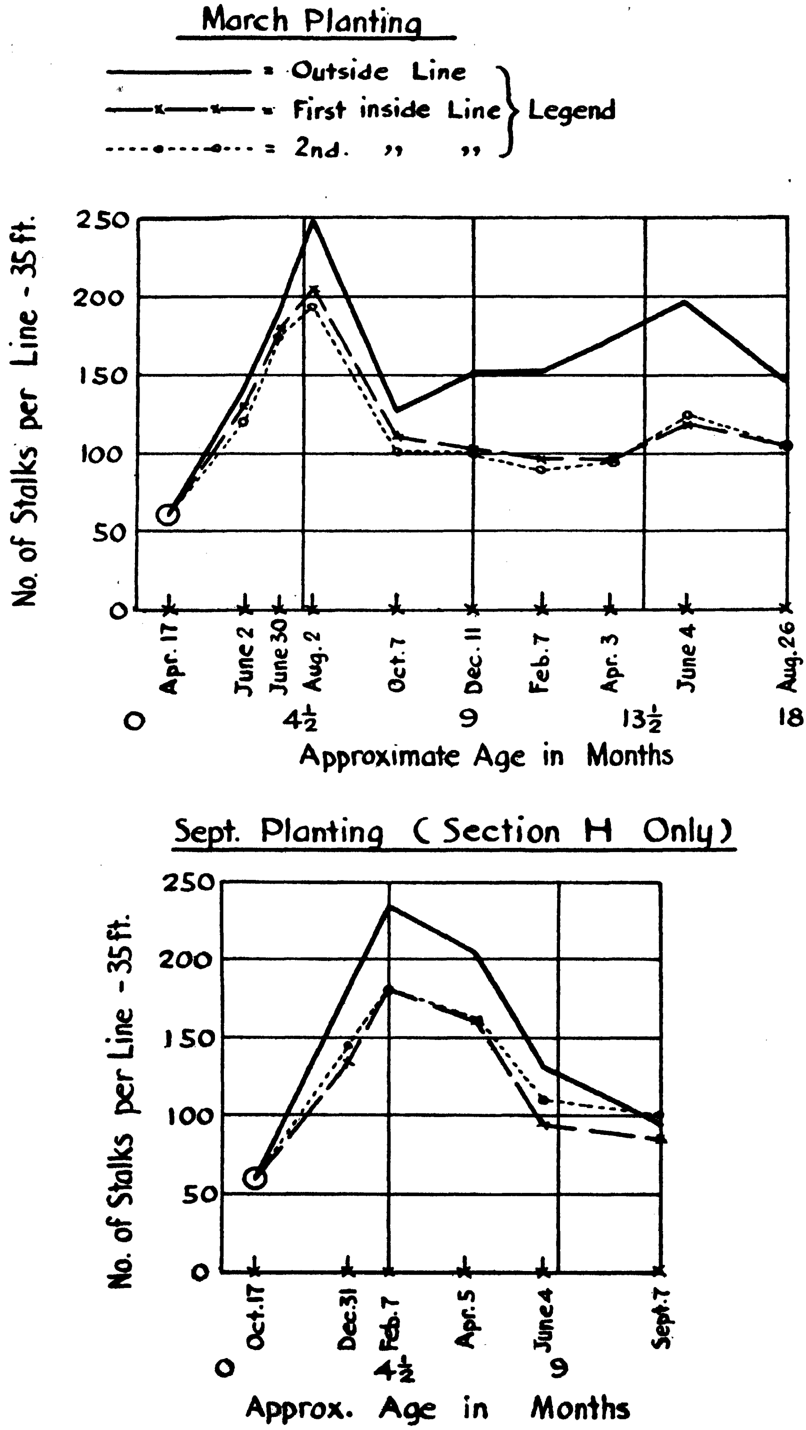


Fig. 3. The figures show the changes in the population of the field at various ages. One month after planting (April 17 and October 17) there are only 35 primary or first-order stalks in each line. The number of stalks then rises to a maximum of about 250 at 4½ months of age. This maximum is immediately followed by heavy mortality, the number coming down to about 95 per line and remaining more or less constant thereafter. The mortality is due to self shading from plant competition and not to the season of the year.

September planting: Sections D, E, G, and H were planted in September. At this time, Sections A, B, C, and F had canes already six months old. The end stools in Sections D, E, and G did not get the full amount of sunlight. The shoot count data in these sections are of great interest in showing the effects of shading. However, for the purpose of Fig. 3 only the data from three rows of Section H are summarized, for this is the only section that was not handicapped by the border effect of big cane. The total number of stools here is only 105, but the progress of suckering is identically the same as in the March planting. Starting with 35 stalks per line at one month the number rises to a maximum at about 4½ months and then declines sharply. Contrary to observations reported by others, this decline starts in the beginning of spring and continues through the spring and summer months. Season of planting or season of the year has, therefore, little to do with the general sucker mortality which takes place in every crop. It will also be observed that in the outside row of Section H, the number of shoots gradually approaches the total of the two inside lines. A study of the layout will show that line 1 in Section H is not an outside line in the sense that line 1 in Sections A, B, or C is. There is only a 2½-foot path separating Section D from Section H. When the cane in Section D had grown large, line 1 in Section H ceased to have the same space and light as a true outside line.

IV. Factors in Suckering

All evidence points to the fact that suckering is predominantly influenced by light and exposure, which factors are materially altered inside a cane field by plant competition.

In both plantings the outside lines have a larger number of suckers than the inside lines. In March plantings the total number of shoots in the outside lines rises to a maximum of 250 per line or about 7 per lineal foot. In the inside line this is about 5½ per foot. At the time of maximum stooling the 24 end stools in the 12 lines averaged 9½ shoots per stool but the inside stools averaged only 6 per stool.

The sudden rise in the number of shoots obtained in December for the outside lines of March-planted cane is explained by the fact that an adjoining field of cane was cut in October. The outside lines, therefore, received an increased amount of light and space which were at once reflected by an increased number of suckers in the outside lines.

The inside lines do not show this effect as will be seen from Table III. Section F, which did not have the benefit of this exposure, also does not show any material increase in the number of shoots.

It has been observed previously that in September-planted cane, the end stools in some of the sections did not receive full sunlight. Some were deprived of early morning light and some of afternoon light. These stools show very irregular and delayed suckering compared with the other stools that received full sunlight. Thus in Section E, in the end stools which did not receive morning light until about ten o'clock, there were no suckers of the second or higher order until after the fourth month. But the point of interest is this: that the same stools caught up with the others in the number of suckers later on. In other words suckering was not

stopped but only delayed. This naturally raises a question as to the exact nature of suckering. Do the plants need a certain minimum or a balance of some essential factors before they will produce suckers? If this condition is satisfied in two months, suckers will start in two months. If it should take six months for the plants to obtain the minimum or the required balance, suckering may well be delayed for six months. The factors may be total quantity of light, heat or some physiological condition within the plant.

Plant competition: In a field of cane, plant competition has probably a more direct bearing on sucker production than anything else. We use the word "direct" purposely, for the factor of competition brings in its train other factors such as available space, light, heat, etc. Let us consider a plant field which has just been started; and has in our case one shoot to a running foot. There is enough space and light for all the shoots to grow and multiply. At first the shoots have small slender leaves occupying but little space, but as the shoots become adult or begin to form millable cane the leaves become broad and big. There is not enough space for all of the shoots to get their share of light. Some of the better placed shoots continue to grow and others are starved, smothered out of existence. This is about the time when we notice the first big mortality in the number of suckers. This fact operates independently of the season, for in both March and September plantings the mortality starts between 4 and 6 months, about the time when millable cane is forming. However, in one case this period comes in the fall months and in the other in the spring and summer months.

After the first big wave of mortality there is a period of fairly stable conditions. Those stalks that have survived continue to grow. Then the time comes when the big canes, being top heavy, begin to lodge. The stable conditions are again altered and where the light penetrates the cane rows new shoots spring up. (Perhaps we should attribute this to the heat that comes with light rather than light *per se*.) If the trash covering is heavy these second-season suckers may not be very numerous. Nevertheless, these suckers are a reality. These new suckers get off to an excellent start, and are very soon competing with the old and fallen cane for light and air. In this struggle sometimes the old ones, but more often the younger ones, survive. It is now the turn of the old cane to begin dying from the top downward. Here begins the commonly observed rotting of the old cane. This picture is well supported by the data on shoot counts and by observations made at the time of harvest.

V. Number of Stalks Per Foot

It will be noticed that both in the March- and September-planted cane, the number of stalks per line is about 95 to 100 or about 2.7 per foot. This figure is essentially the same as reported previously by various workers in these Islands. But the point of interest is this, that in the March-planted cane, the maximum number was higher both in the outside and the inside lines than in the September-planted cane, but at 12 months and thereafter both plantings had the same number of stalks per line. On the one hand, it appears as though H 109 under the experimental conditions can support no more than 2.7 stalks per foot of line: as though the leaves of these stalks fully utilized all the light and air that are avail-

able over a foot of soil, leaving no room for further leaf production (in canes with smaller leaves this number should undoubtedly be greater). On the other hand, it raises the question: Is it of any advantage to have a large number of suckers to start with if we always end with the same number? Is the March planting better than the September planting?

Sucker mortality is a natural phenomenon and we shall not possibly be able to stop it, but nevertheless the writer feels that this is at best a necessary evil, necessary in the sense that a large sucker growth seems to be correlated with that much-sought-after quality of cane—namely, vigor; and evil, because in the opinion of the writer, sucker mortality represents much wasted effort and very probably some wasted material.

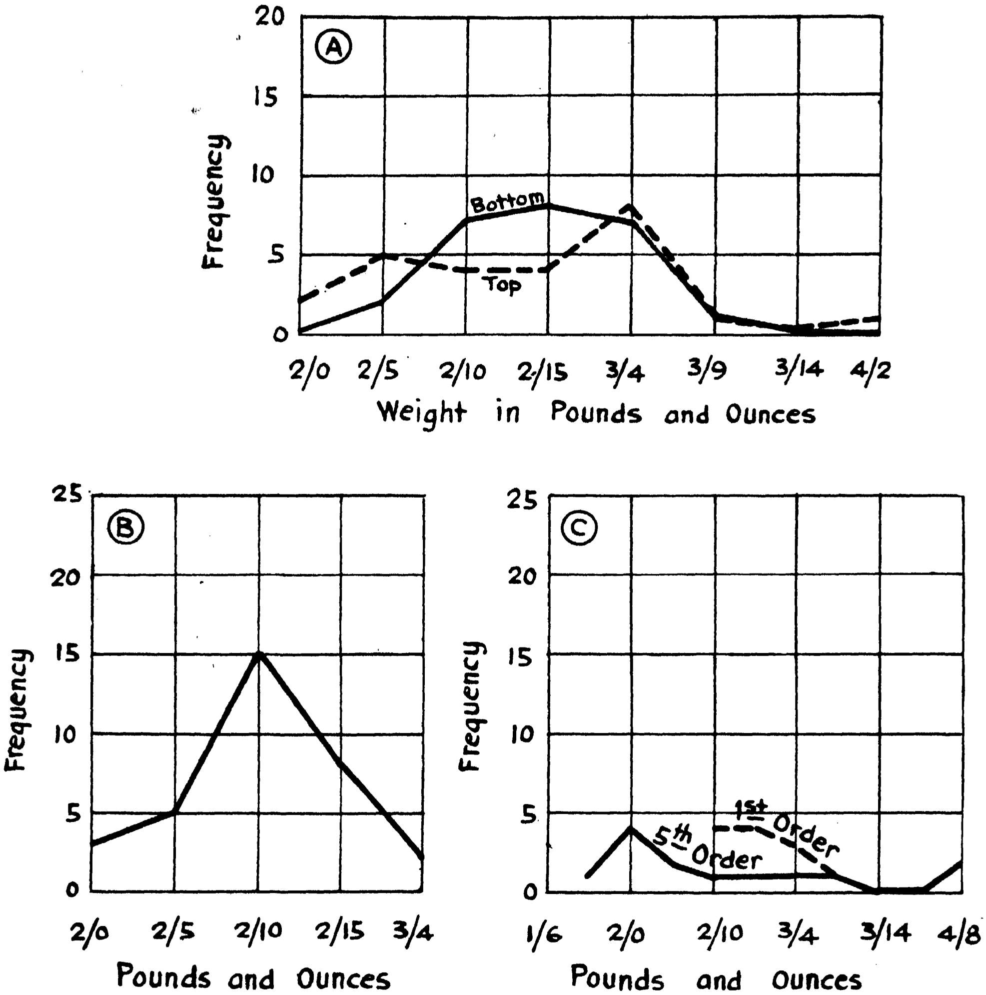
VI. Border Effect

Fig. 3 shows that a change in the exposure outside of the field affects the outside lines only. Even the first inside lines of March-planted cane do not show the same fluctuations as the outside lines. It would, therefore, appear as though one single line of cane was well able to protect an inside line from extraneous influences of exposure.

VII. Variations in Stalk Weights—An Index of Variable Field Conditions

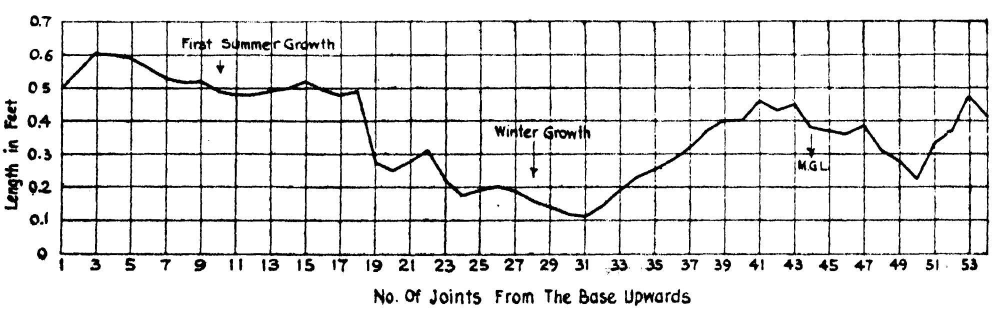
It has been previously stated that one is always confronted with great variations in studying sugar cane. Variations have been noted in the nature of suckering and number of suckers. We shall now discuss variations in weight which are to be found in various parts of the same stalk. We shall consider this aspect of quality of the different parts of a stalk at a later stage when we take up the question of juice quality.

If we take the weight of the bottom four feet of cane of the first-order stalks, we find that it is less variable from stalk to stalk than the top four feet of millable cane of the same stalks (Fig. 4). In one harvest, at 18 months, the coefficient of variation of the bottom parts was 0.23 pound and of the top 0.53 pound. In another harvest, at 25 months, the figures were respectively, 0.19 pound and 0.29 pound. Similarly, we find that the second-order stalks have more variation within themselves than the first-order stalks, and each higher order is more variable within itself than the orders preceding. The picture which we get from these data is this: When a field of plant cane starts we have a relatively small number of shoots. Each shoot has ample space to grow, ample plant food, etc., and consequently all can grow about equally well. But as the stalks grow big and new numbers arise to compete for light and food, some are placed to advantage and some otherwise. Some have probably lodged, and before they can come to unobstructed light others have crowded into the space, leaving the former to eke out a mere existence. Greater proximity to plant food, freedom from disease, etc., are also contributory causes to this variation. In other words greater variations in growth at later stages reflect greater variability of growing conditions within the field.



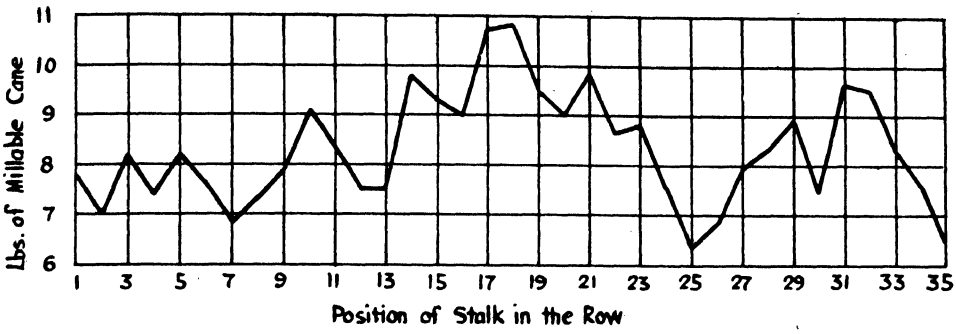
A—Top and bottom 4-foot lengths of first-order stalks.
B—Second-order stalks, same line.
C—Fifth-order stalks and bottoms of first-order stalks in the same stool.

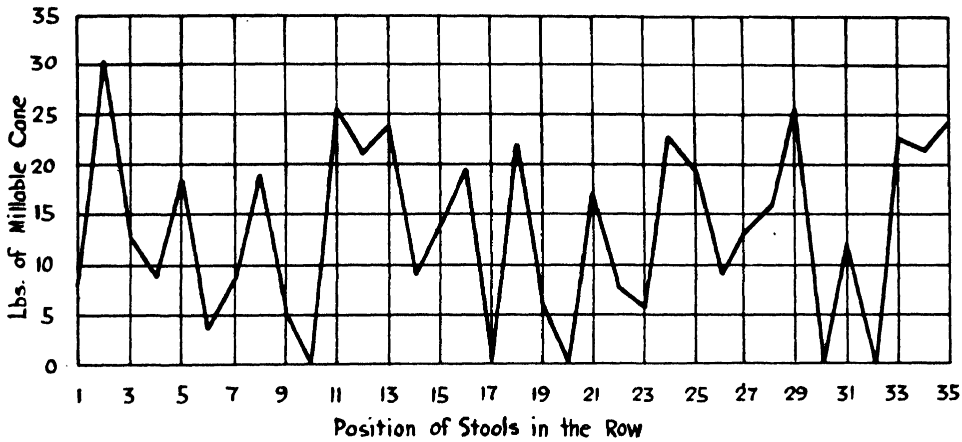
Fig. 4. These figures attempt to show that as the crop proceeds, growing conditions become more variable inside a cane field. The weight of the bottom 4 feet of the first-order stalks shows a normal distribution suggesting more or less uniform growing conditions. The weights of the top 4 feet of the same stalks are more variable as a result of variable conditions. The second-order stalks show a little more variability than the first-order stalks, while the fifth-order stalks which had their existence entirely under variable conditions show even greater variation in weight.



Length of each successive joint of a second-order stalk.

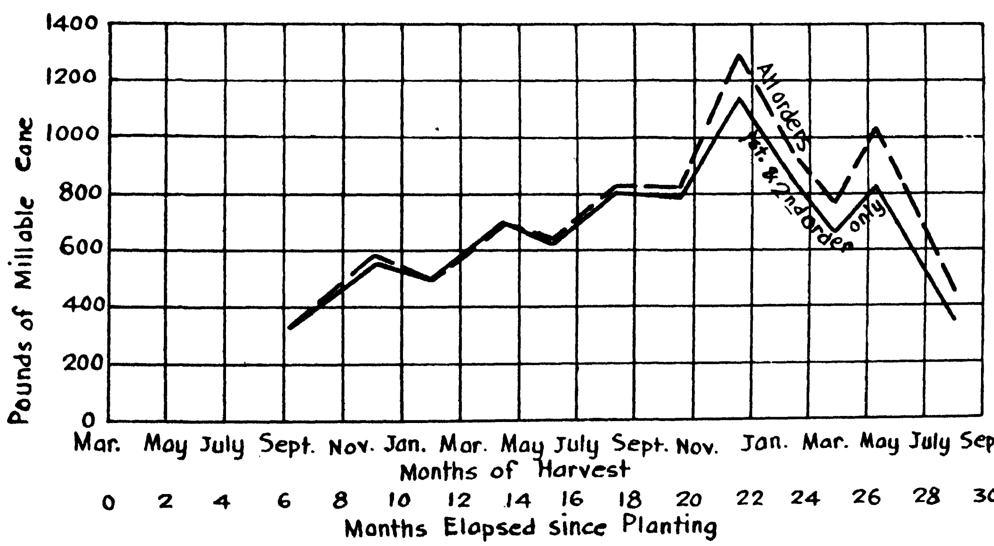
Fig. 5. Showing the variations in the length of joints caused by the seasons of the year. These variations are the usual rule in a cane field.





Showing the variation in the total weight of second-order stalks in the stools, the primary stalk weights of which are shown above.

Figs. 6 (above) and 6-A (below). In this particular experiment, in spite of careful plans working towards a uniform stand, we still find a great deal of variation in the weight of successive first-order stalks and of second-order stalks in successive stools of cane.



The proportion by weight of first- and second-order stalks in the total weight per line. (March planting.)

Fig. 7. First- and second-order stalks composed from 80 to 100 per cent of the total weight of millable cane harvested in this plant field. Under the experimental conditions, the second-season suckers play a minor role.

Probably no two internodes of sugar cane are ever alike in length or weight, influenced as they are by seasonal and other factors. Those of us who are familiar with the cane plant know of this seasonal variation. A typical example of the joint-to-joint variation in length of successive internodes of a stalk can be seen in Fig. 5.

This was a second-order stalk of March-planted cane harvested in September at the age of 18 months. It is quite evident from the chart that during the first summer the joints were long, they were shortest during the winter and they lengthened again the following spring and summer.

Fig. 6 shows variations in the weight of millable cane of first-order stalks from the same line, and Fig. 6-A of the second-order stalks from each successive stool of cane, also of the same line. In the case of second orders, the variations are naturally due to weight of stalks as well as number of stalks, for neighboring stools seldom have the same number of second-order stalks. And so we may go on giving instances of variation which are encountered at every step, all of which makes a study in crop variation a complicated task.

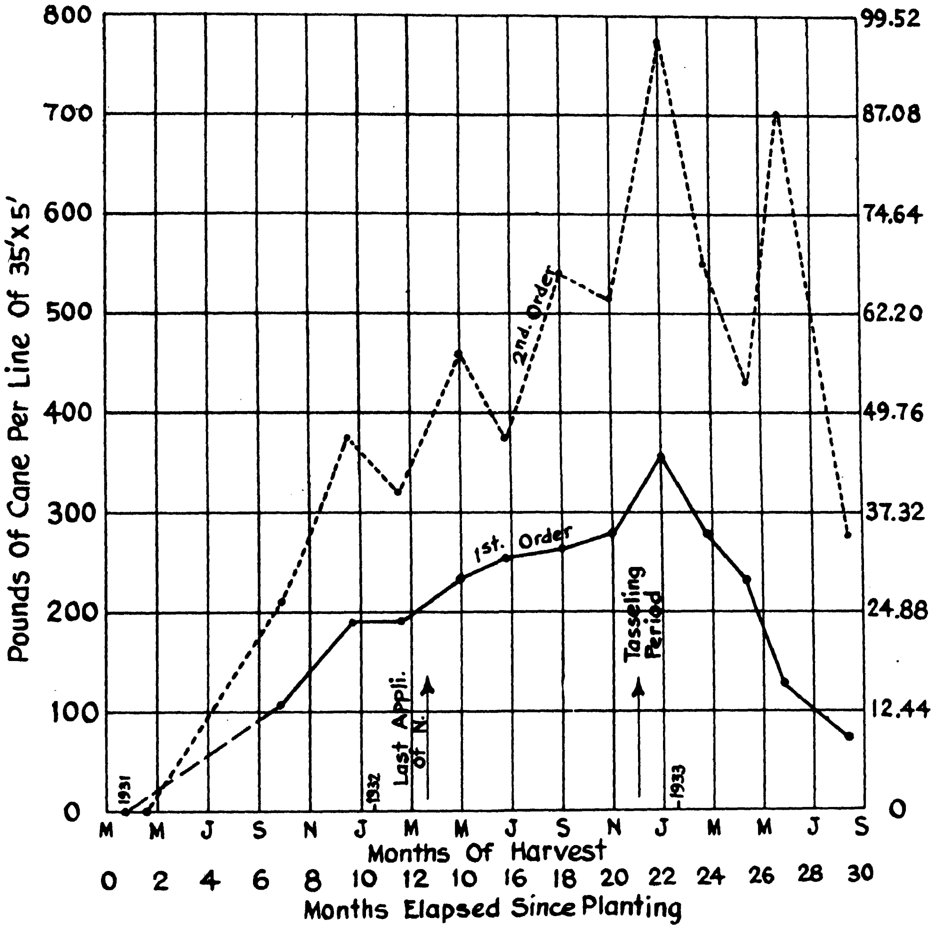
VIII. Millable Cane

March planting: Beginning at six months of age and about every two months thereafter, one or two lines of cane were harvested. At each harvest the stools were cut one at a time and the stalks of different orders segregated. The stalks of the same order in each stool were then weighed separately. Thus we have very detailed data on weights of millable cane and non-millable top in every line at each harvest.

Proportion of stalks of first and second order: In the experiment as planned and carried out* we find that the first- and second-order stalks average about 80 to 100 per cent of the entire number of stalks harvested at any one time and Fig. 7 will show that these stalks compose an even greater per cent by weight of the total cane harvested. For an evaluation of the crop progress in this experiment we need, therefore, consider in detail only the stalks of the first and second order—that is the stalks which came out within the first three months after planting.

Weight of millable cane of first and second order: Table IV and Fig. 8 show the weight of millable cane at various ages and seasons of harvesting. In the first-order stalks the cane weight increases steadily to about 22 months and is followed by a rapid decline, so that the weight of cane at 29 months is less than at 7 months. The weight of the second-order stalks also increases, but with less consistency, to a maximum at about 22 months and declines thereafter quite as rapidly as in the first-order stalks. An analysis of the harvesting data shows the fluctuation in the weight of the second-order stalks at various ages to be caused by variations in the number of stalks harvested rather than by their weight. Elsewhere we have remarked that with all our care and planning, we have been unable to make the different lines of cane contain a uniform number of stalks. However, the trend of increasing yield is so evident that we may overlook these fluctuations as the unavoidable experience of field culture.

* We use the words "as planned and carried out" advisedly. We do not know what the proportions would have been if the original stand were thicker or thinner.

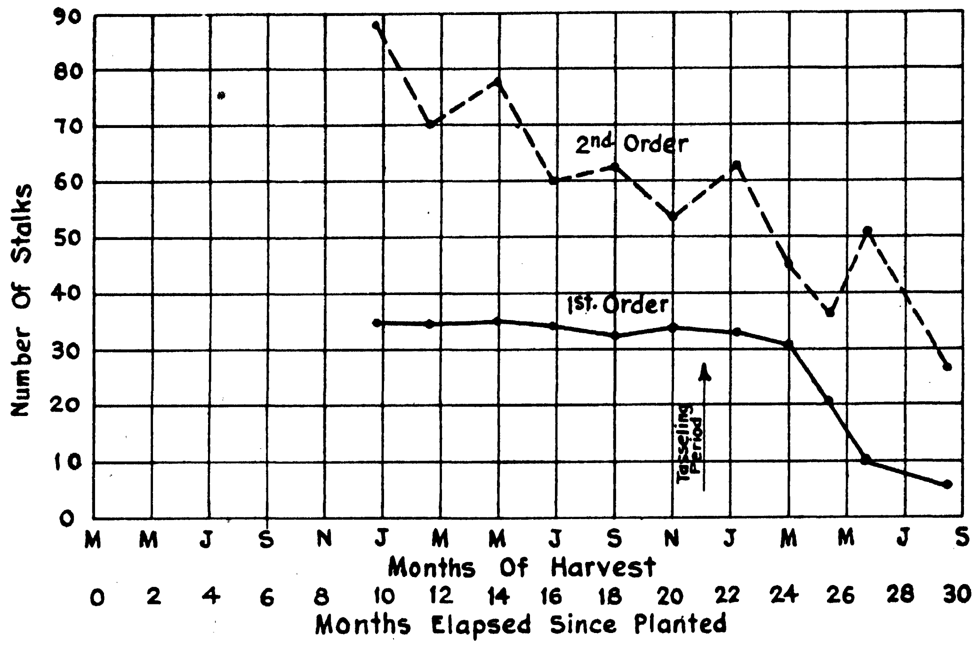


Weight of millable cane at various ages.
(Planted March 17, 1931.)

Fig. 8. The total weight of first- and second-order stalks rises steadily to an age of about 22 months, followed by a rapid decline. It is suggested that the decline is due to the field going back after tasseling. The fluctuations in the weight of the second-order stalks are caused by fluctuations in the number of stalks harvested.

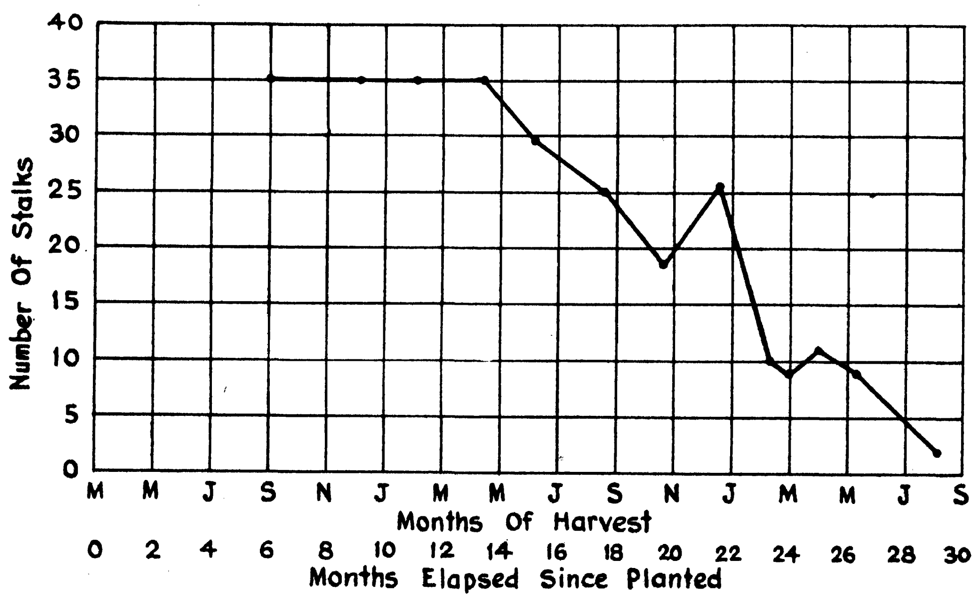
Discussion: The rapidity of the decline in cane weight after the January, 1933, harvest at about 22 months of age, has been due to the steadily mounting mortality of stalks, as will be seen from Fig. 9.

As a probable explanation of the cause of this mortality we offer the following: In this planting there were practically no tassels in the first year, but the following November (1932) the field tasseled very heavily. Tasseling as we know brings to an end the terminal growth of the stalk. The stalk has no actively assimilating leaf surface of its own. It must either gradually deteriorate or survive only if the terminal nodes can send out lalas (or side shoots) which can carry on the process of assimilation, thereby keeping the tissue in the mother stalk in a healthy condition. Very few lalas were, however, noticed on the March-planted cane and it is our belief that the majority of the stalks started inevitably to deteriorate because they were unable to send out lalas. This absence of lala growth may be traced to the lack of vegetative vigor in this 22-month-old field of cane. It will be remembered that our last application of nitrogen went in at 12 months of



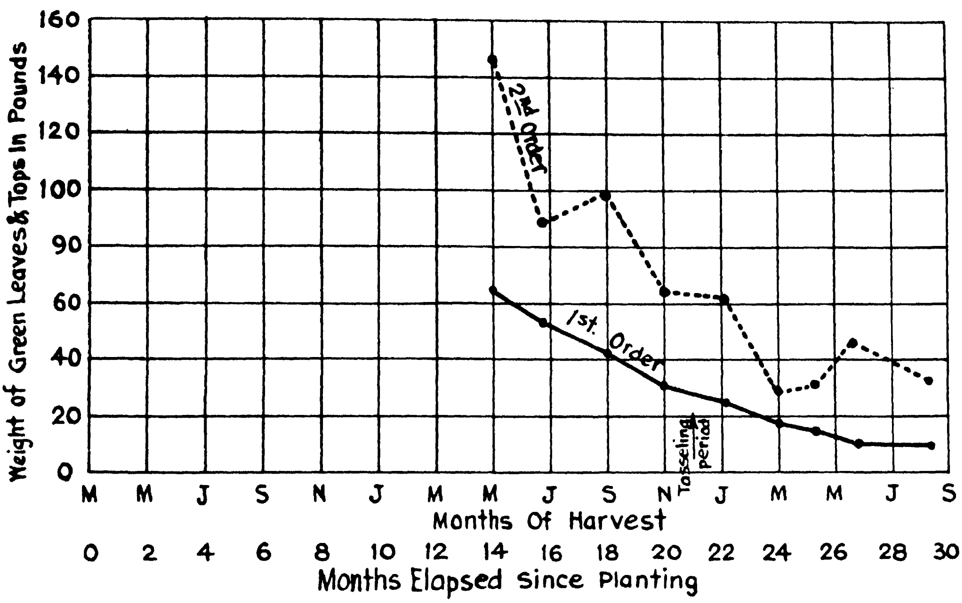
Number of stalks harvested per line on various dates.

Fig. 9. The number of stalks gradually decreases as the field gets old. Note the rapid decline in number after the twenty-second month resulting from mortality after tasseling.



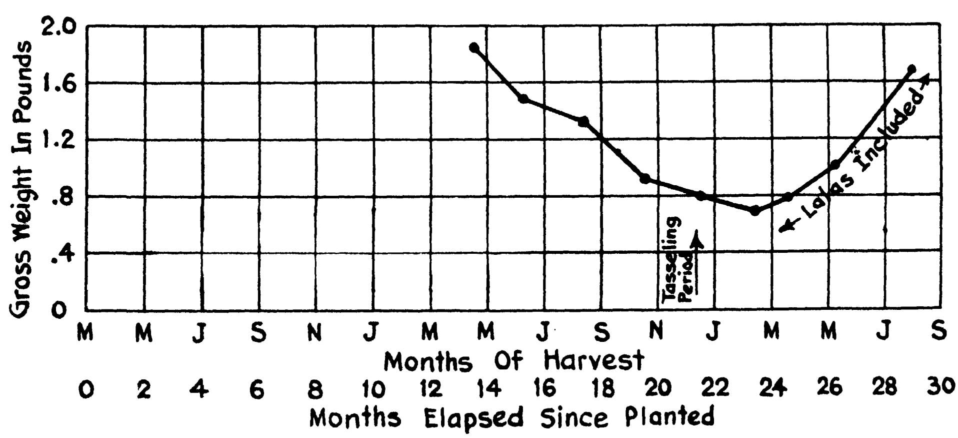
Number of healthy primary stalks harvested at various ages. Original number, 35.

Fig. 9-A. Deterioration of first-order stalks appears to start at about 14 months. This deterioration is probably due to plant competition accentuated by the declining vigor of some stalks due to old age.



Showing the weight of green tops at different ages.

Fig. 10. The weight of green top is highest in the first year of the field. Under experimental conditions the weight decreases steadily indicating decline in vegetative vigor.



Average weight of green top of primary stalks. (March planting.)

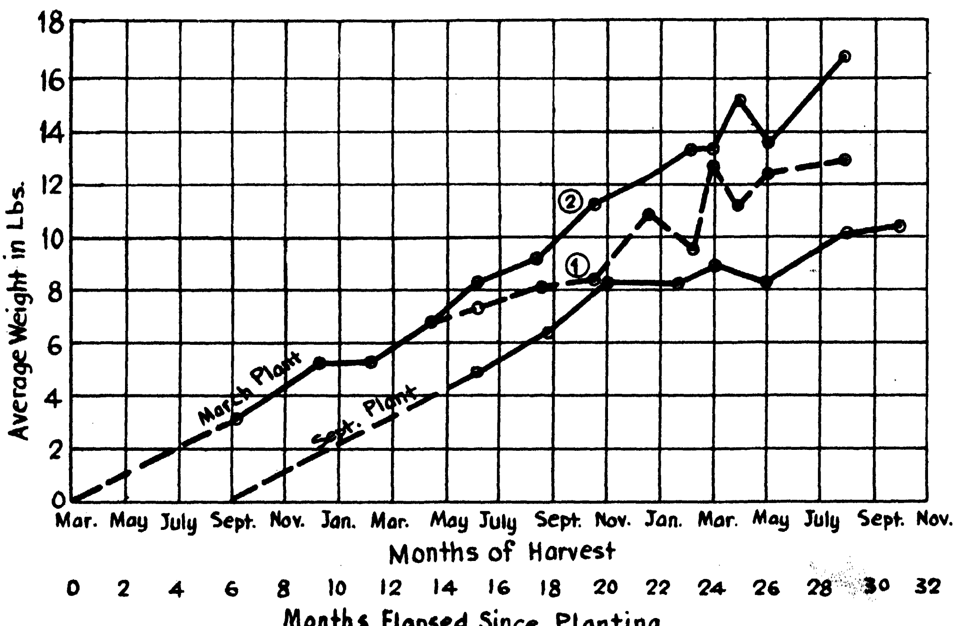
Fig. 10-A. The average weight of green top on a first-order stalk decreases very rapidly in the second season. After tasseling there is an apparent increase caused by lalas.

age or fully 9 months previous to tasseling. The declining weight of non-millable green tops at various ages (Fig. 10) also supplies additional evidence in support of our statement concerning lack of vigor.

Number of stalks at various ages: Table V and Fig. 9 show the number of stalks harvested at various ages. We see at once how rapidly the number goes down, especially after November, 1932, i.e., after tasseling. Excluding the stalks which were partly decayed, we find the picture even more striking (Fig. 9-A). Deterioration appears to start in the first-order stalks between 14 to 16 months of age and from then on it proceeds rapidly so that at the age of 29 months we have out of 35 original stalks only two which were entirely healthy. However, this deterioration is a more gradual process than the rapid decay which follows tasseling.

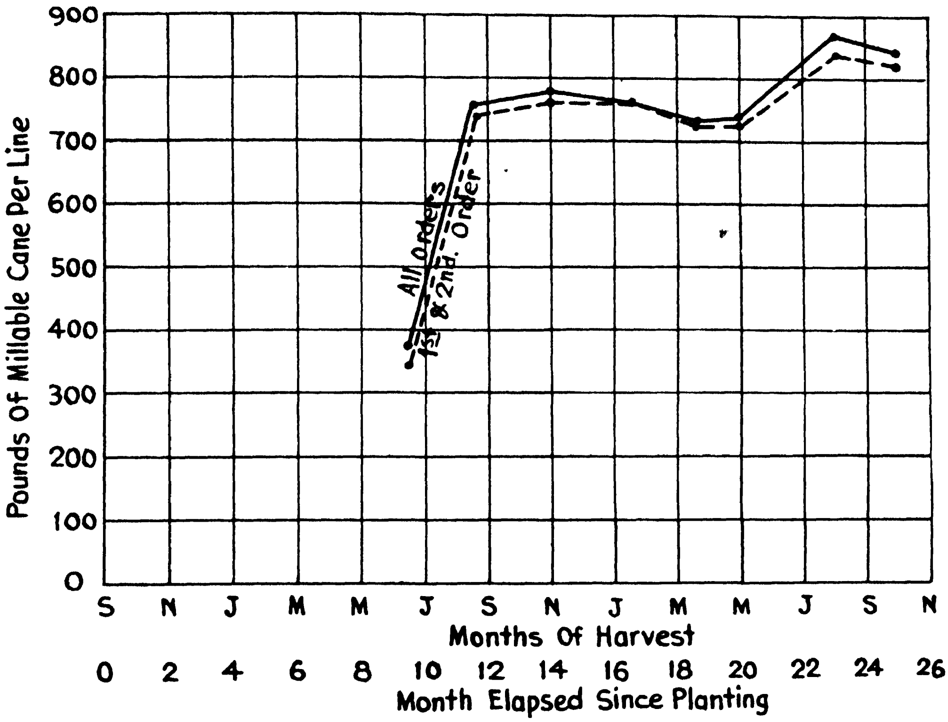
Weight of green top: In Table IV and Fig. 10 we see that the weight of green top also declines rapidly as the cane grows old (we did not keep data on green top prior to April, 1932). This decline is due to the decrease in the number of stalks as well as the average weight of the top of a single stalk. Table VI and Fig. 10-A shows that the weight of green top of an average primary stalk fell lower than 0.7 pound of weight at 23 months from a value of 1.8 pounds at about 14 months. After 24 months there is apparently an increase in weight again in the few surviving stalks due to the green weight of lalas.

Average weight of first-order stalk: Table VI and Fig. 11 show the average weight of a first-order stalk at various ages. The weight goes on steadily increasing at first and then there is a tendency for the curve to flatten out as large num-



Average weight of primary stalks at various ages.
1—Inclusive of cane with dying tops.
2—Exclusive of cane with dying tops.

Fig. 11. Increase in the weight of the first-order stalks appears to be uninterrupted to an age of 29 months. Decrease in the total weight therefore results from loss of number rather than the weight of stalks.



Total weight of millable cane in all orders of stalks harvested at different dates compared with the weight in the first- and second-order stalks only.

Fig. 12. In September-planted cane second-season suckers are almost non-existent, the first- and second-order cane forming over 95 per cent of the total crop.

bers of partly deteriorating cane are being included. If, however, we confine our analysis only to those stalks that carry a healthy top, we find that the increase in weight is quite steady to the age of 29 months.

September planting: Similarly as in March planting, one line of cane was harvested at intervals of about 2 months beginning at the age of 9 months.

Proportion of first- and second-order stalks: First- and second-order stalks in September planting constitute an even greater proportion of the total weight and number of stalks per line than in the March planting (Fig. 12). Whereas in the March planting we had at times 10 to 12 per cent of the total weight in second-season stalks, in September planting we had at no time more than 2 per cent in stalks other than first and second order. This difference in the crop composition of the two seasons of planting is of interest and may under certain circumstances be of significance.

Weight of millable cane: Table VII and Fig. 13 show the weight of millable cane harvested at various ages. In contrast to the figures presented for March-planted cane, here the weight increases up to about 14 months and then there follows 6 to 8 months of no increase or decrease and a very slight increase thereafter at 22 and 25 months. The sudden jump in the weight of second-order stalks around 12 months is due to an unusually large number of stalks of that order being harvested at that time. If we allow for this variation in number, we find the total weight of the second order to be about 100 pounds less.

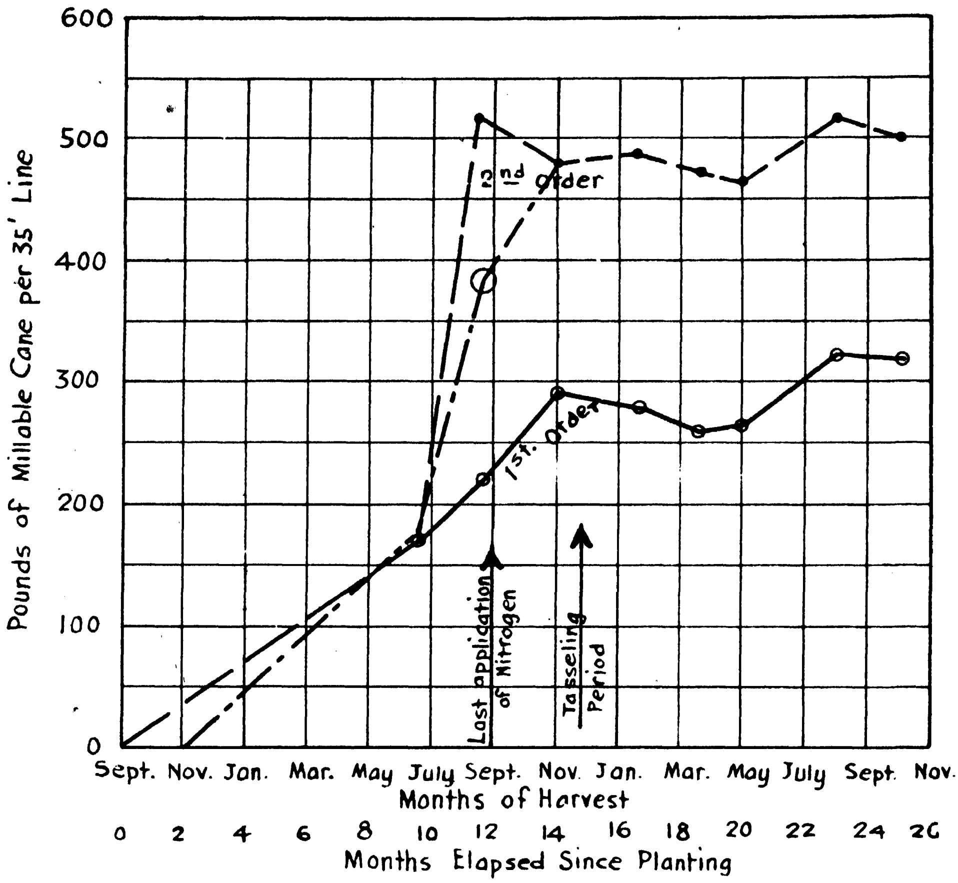


Fig. 13. Contrasted with the March-planted cane, there is hardly any increase in weight of cane harvested after about the fourteenth month. We believe that this static condition is also due to the effects of tasseling. As the lalas become millable there is a slight increase after the twentieth month.

Discussion: These results further support our contention that the effect of tasseling and the time of last fertilization have an important bearing on crop yield. This cane, planted in September, 1931, tasseled in November, 1932, or at the age of about 14 months. Only two months previously, or at the age of 12 months, the plots had received their last application of nitrogen, at the rate of 50 pounds per acre. As opposed to the March-planted cane, this September-planted cane still had much vigor left (as the weight of green tops will indicate), with the result that these canes sent out lalas soon after tasseling and managed to survive. We have actually observed more lalas in this cane than in the March-planted cane. Most of these lalas formed millable cane later and this fact explains the slight increase in yield at about 22 months of age and thereafter. There were 6 to 8 months of static condition during which period no millable lalas were being harvested. It is our belief that in this plot a large number of tasseled sticks were standing still while the lalas were slowly coming to be millable and in the case of the remaining stalks the natural deterioration of some stalks was offset by the increase in weight of others so that the net gain was still nil. Even though the greatest total weight of cane was harvested at 23 months, there is no question that a plantation would have been justified from considerations of per-acre-per-month value to harvest a sim-

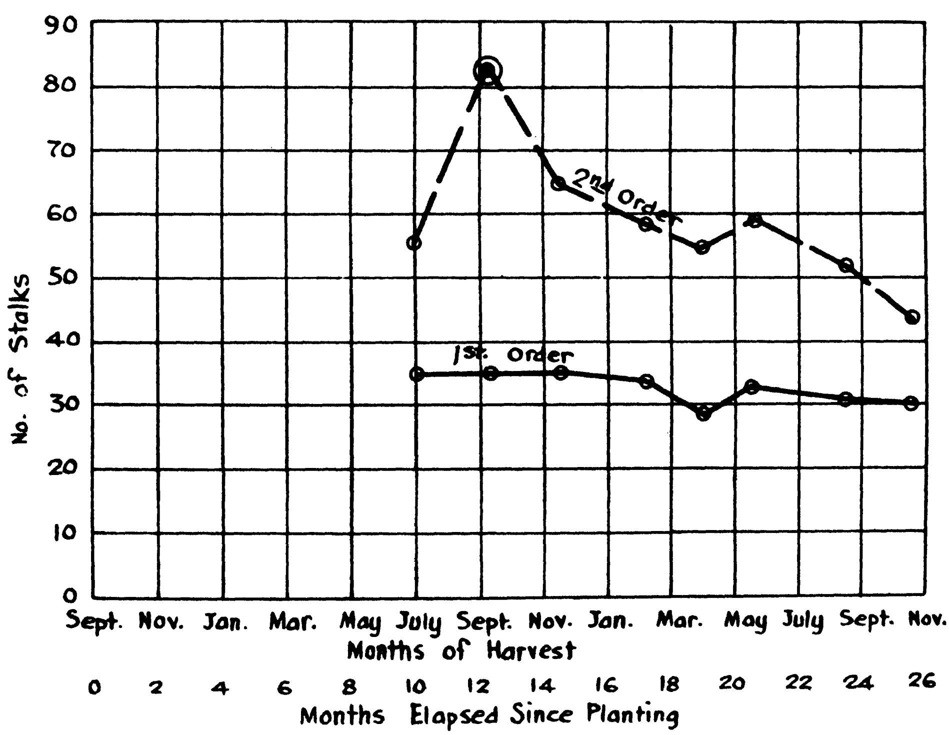
ilarly affected area at about 14 to 16 months of age or soon after tasseling. By so doing the unproductive months that followed tasseling could have been utilized in growing a good ratoon crop.

It must not be understood that we are bringing up here the issue of long or short crops, a much broader question and one which involves many other factors. Tasseling alone may not determine whether to cut a field long or short, for there may be ways and means by which even tasseling or its after-effects could be controlled.

Our results suggest that a close study of the condition of the field and better knowledge of how to interpret what the cane crop has to tell us may be very helpful in settling some of the moot points bearing on the proper length of crop.

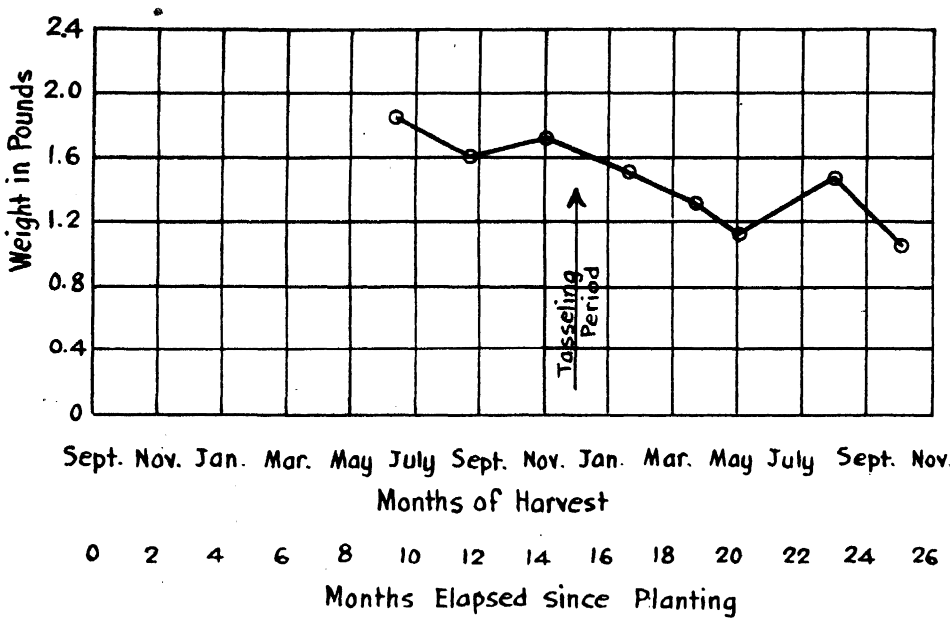
Number of stalks at different ages: Table VIII and Fig. 14 show that the number of stalks harvested does not fall off as rapidly in the September-planted cane as in the March-planted cane. We would expect this to be so, knowing that rapid emergence of lalas after tasseling had kept the big cane from deteriorating.

Weight of green top: In Table IX and Fig. 15 we see that the weight of green top decreases similarly to March-planted cane from a high value to about 1.8 pounds per average first-order stalk at 9 months of age to a little over 1 pound at 25 months. At no time does the value fall as low as 0.7 pound—the lowest value for March-planted cane. Just prior to tasseling the average stalk had a top weighing 1.6 pounds. In March-planted cane the top was less than 1 pound at that time—



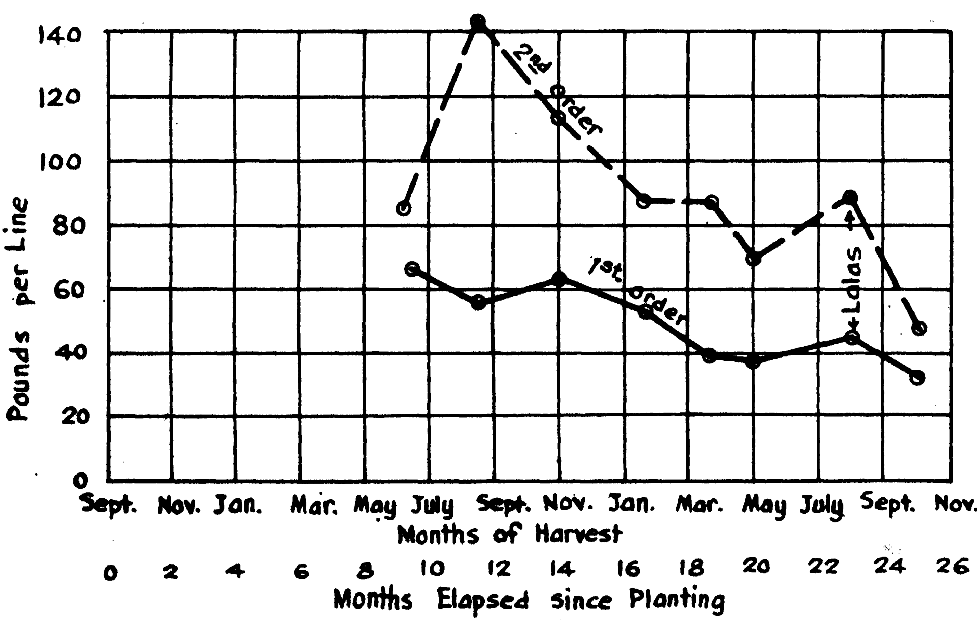
Number of stalks harvested on different dates. (September planting.)

Fig. 14. In this planting the number of stalks does not fall off in the manner observed in the March planting. It has been suggested in the body of the report that this difference may be attributed to the time of application of fertilizer in relation to the season of tasseling.



Average weight of green top of first-order stalks. (September planting.)

Fig. 15. Note that at no time the average green weight of non-millable tops falls to such low values as were found in the March-planted cane.



Total weight of green leaves and tops. (September planting.)

Fig. 15-A.

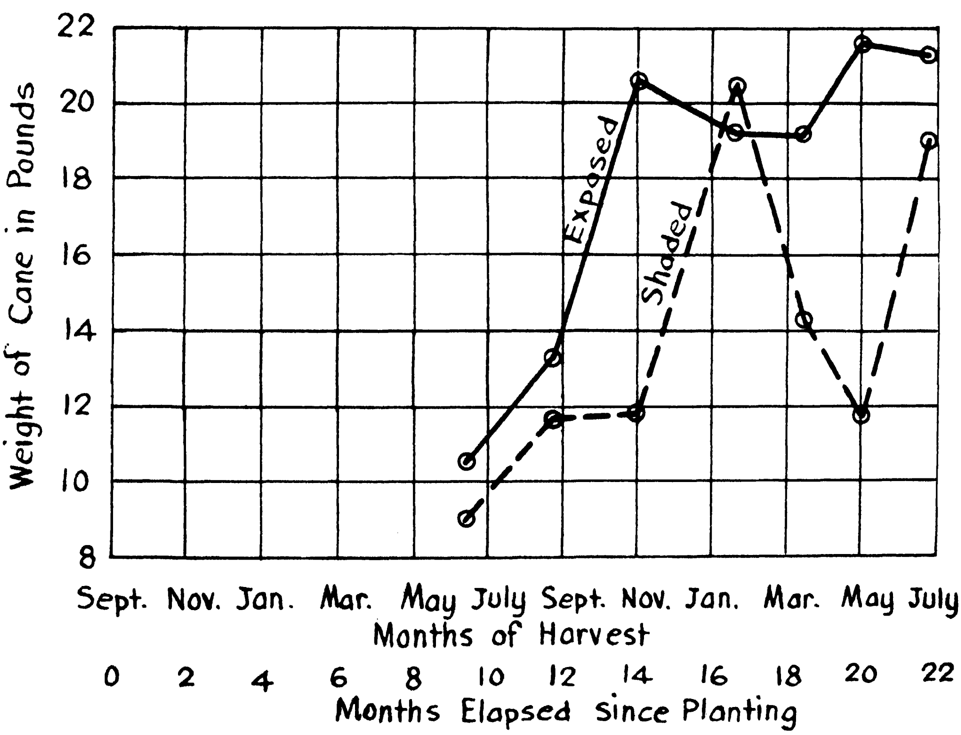
again supporting our belief that the September-planted cane had greater vegetative vigor.

The total weight of green matter per line is seen, as in the other planting, to be highest when the cane is about 9 months old, the weight decreasing steadily thereafter (Fig. 15-A).

Shaded vs. exposed cane: In connection with suckering, we stated the fact that one end of section E of September-planted cane was shaded in the mornings by an adjoining field of cane with the result that this end was delayed in suckering and was otherwise weak at the start. In harvesting this plot we always separated the exposed end of the plot from the shaded end, so as to study the variations at different ages. Table X and Fig. 16 show that the weight of cane in a running foot of row in the shaded section was much lower, with one exception, than in the exposed section. (It should be stated that shading by the adjoining cane ceased to be a factor when the September-planted cane grew big. After the first 8 or 10 months, there was therefore no shading effect to speak of.) These results would suggest that the tremendous handicap of a poor start can not be wholly made up by equal conditions later on.

IX. Juice Quality

The problem of juice quality is even more complicated than problems of cane weight. Juice quality is affected by all the factors that cause variation in cane weight and many more. The average quality of juice from a field of cane is



Average weight of millable cane per stool (one-foot row) in the shaded and exposed parts of the same line of cane.

Fig. 16. Plants that were shaded for several months early in life weighed less than those plants that were continually exposed.

usually a composite of all the different orders of stalks growing in the field. The proportion by weight of the different orders and their respective quality will then be the determining factors.

Then there are other factors such as variation in quality in different parts of the same stalk, the effect of tasseling and forming lalas, the effect of season and weather conditions, cultural practices, etc. If the problem is more complicated, then the need for precise knowledge leading to an understanding of it is also greater. In the following pages we shall first take up a general discussion of the average quality in the whole stalks, to be followed by a detailed discussion of quality in different parts of the stalks.

Method of extraction and definition of quality: At each harvest the different orders of stalks were made into composite samples and the total weight of cane was run through a three-roller Cuba Mill having an extraction of about 50 per cent of juice. By so taking the total weight, sampling errors were avoided. The juice samples were then analyzed by the Sugar Technology Department of the Station for Brix, polarization, sucrose, glucose, and purity. Juice quality in this paper refers primarily to the percentage of sucrose and glucose in the juice, as these two quantities are generally sufficient for an understanding of the true quality of cane.

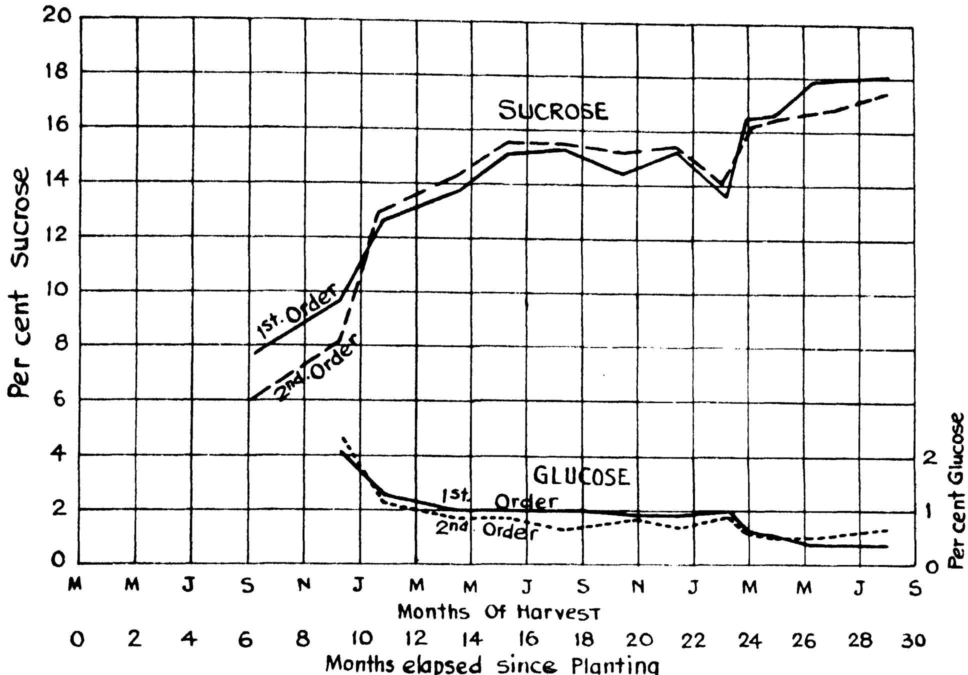
March Planting:

First- and second-order stalks: Table XI and Fig. 17 show the per cent of sucrose and glucose in the different orders of stalks at various dates of harvesting. These figures show clearly that the per cent of sucrose goes on steadily improving to an age of 29 months. In cane more than 24 months old we have obtained juices of 16 to 18 per cent sucrose, of 93 to 94 per cent purity, and 7 or less quality ratio. (Quality ratio is the theoretical tons of cane required to produce a ton of sugar.) In other words there is no evidence to indicate that there is an inherent disposition in cane to deteriorate after it has grown for two years or more.* In this connection it must also be remembered that this excellent quality of juice was secured even without any attempt to "ripen-off" by withdrawing water from the cane for any length of time before harvest. The cane was receiving four inches of water a week to the very last day.

Stalks of higher order: In Fig. 18 we see that the stalks of third, fifth, and sixth order also improve steadily to the last. In fact at around 24 to 29 months after planting, these second-season suckers, meaning the stalks of fifth and higher orders, were just coming of age, so to speak, with a high percentage of sucrose in juice. The point of great interest is that these late suckers, contrary to our belief at the start of the experiment, proved to be capable of making as much or more sucrose than the first-season cane. With this variety and under the conditions of the experiment there is, therefore, no reason to fear lowering of average quality due to inclusion of well developed second-season suckers in our long plant crops.

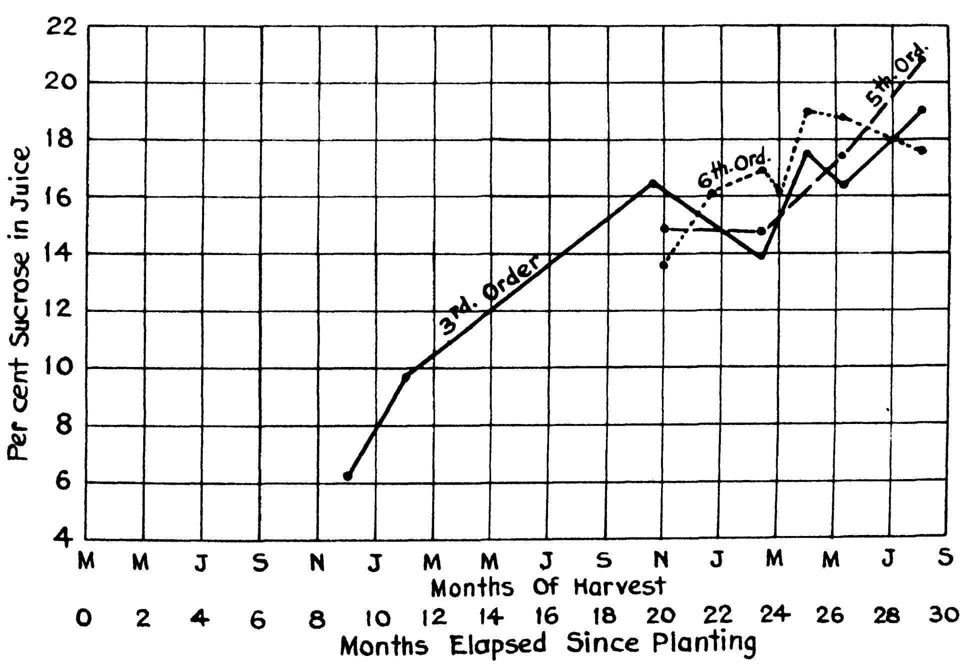
Percentage of sucrose in stalks of different orders at various dates: The data in Table XI have been so arranged in Fig. 19 as to permit ready comparison of

* In one respect our harvest probably differed from plantation harvests, in that we carefully excluded all deteriorated cane.



Percentage of sucrose and glucose in stalks of different orders. (Cane planted March, 1931.)

Fig. 17. In spite of a continuous application of 4 inches of irrigation each week and no attempt at ripening by withholding water, the quality of juice steadily increases to an age of 29 months. There is no indication of the gradual deterioration of juice due to the age of the cane stalks. Poor juices in old fields of cane may be due to dead and dying cane here excluded from consideration.



Per cent of sucrose in juice of third, fifth and sixth orders of sucker at various dates.

Fig. 18. Contrary to the generally held belief, the second-season suckers have been found to be quite as rich in sucrose as the first-season cane.

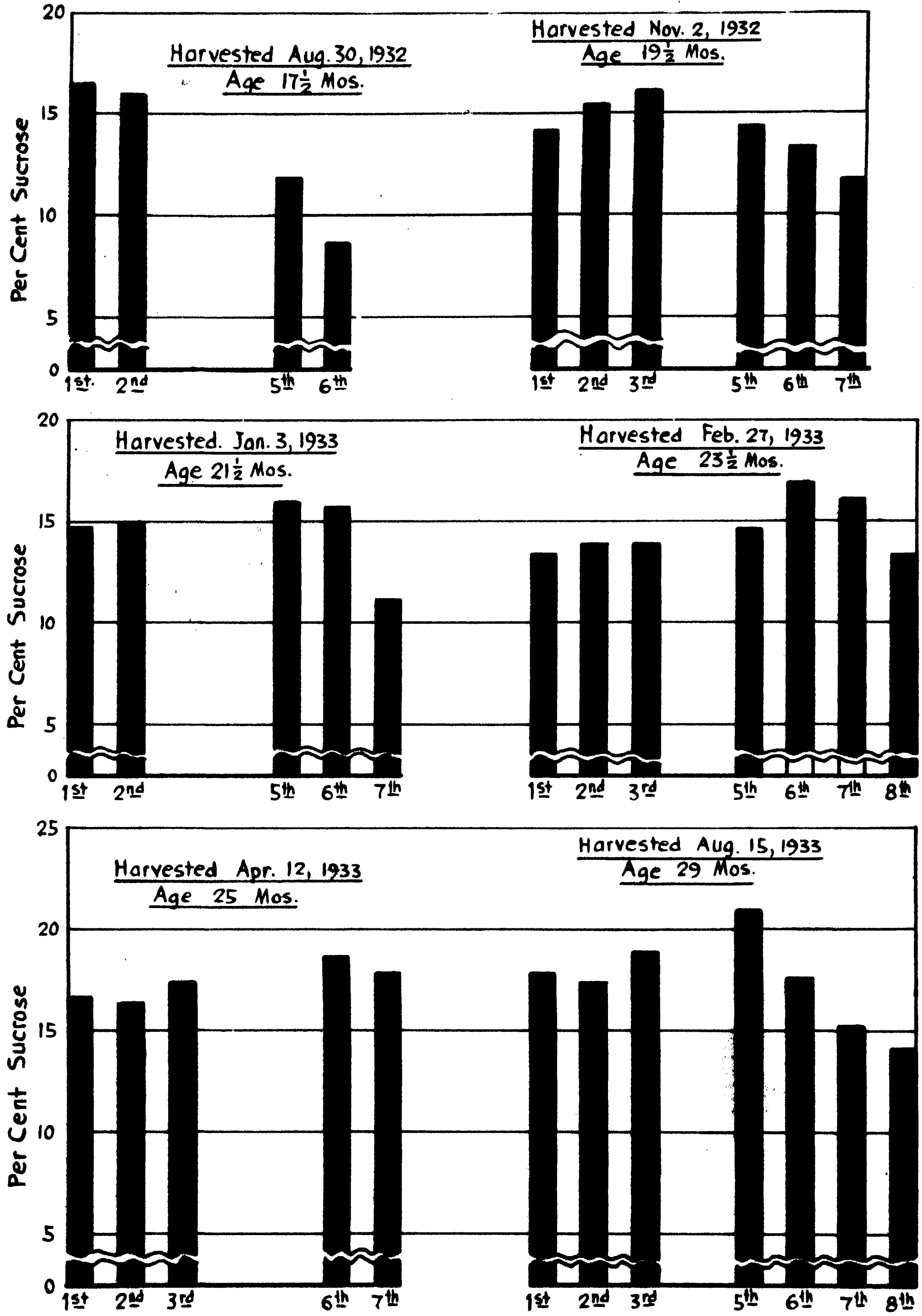


Fig. 19. Shows the percentage of sucrose in the juice of different orders of stalks at various ages. At 17 months of age the first-order stalks have the maximum sucrose content. At each successive harvest the maximum tends to shift to higher orders. (The harvest at 29 months is not quite normal; the field had deteriorated a great deal and the few surviving suckers were of poor appearance.) There also appears to be a trend towards a higher maximum as higher orders come to their peak.

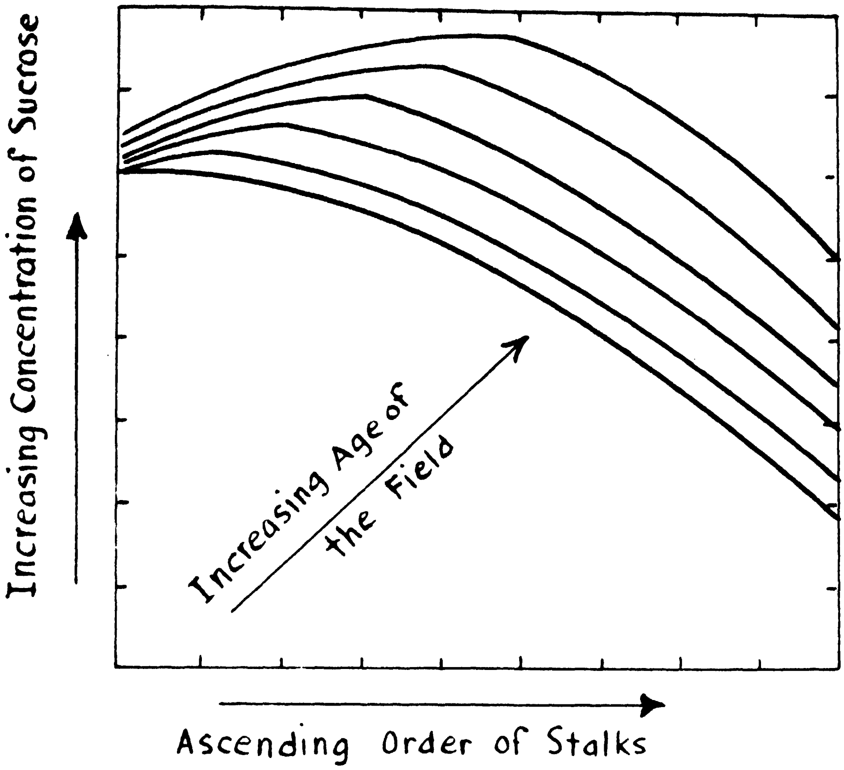


Fig. 19-A. On the basis of the results shown in Fig. 19, we here offer a simple diagrammatic scheme of the progress of sucrose accumulation in a field of cane under experimental conditions. The essential feature of the scheme is that each successive order comes to have the maximum sucrose in its turn and this maximum is probably a little higher than the one previous.

the percentage of sucrose, etc., in different orders of stalks at various dates of harvest from the sixteenth month on. In the first figure, the maximum sucrose content is found in the first-order stalk, two months later in the third-order stalk, and another two months later in a stalk of higher order and so on. Not only does the maximum point appear to shift from the lower to the higher order as time goes on, but also there appears to be a tendency for each subsequent maximum to be a little higher than the one previous. On the information provided by the meager data, we offer a diagrammatic representation of how the concentration of sucrose may vary with time in stalks of different orders (Fig. 19-A).

This diagram suggests that each order beginning with the first comes to its peak in turn. Thereafter its sucrose content remains more or less static—increasing or decreasing a little as the cane remains healthy or deteriorates. In the meantime the next order is rising to its peak, but the peak of the latter is slightly higher than that of the previous order. We believe it will be readily granted that our diagram is sound regarding the first point, that is, the order of time in which different orders come to maturity, but there will probably be hesitation in accepting the other point that each successive peak is higher than the previous. In partial support of our statement we draw attention to the following facts: Our joint-to-joint analysis of first- and second-order stalks shows that the top sections of the big cane have a higher concentration of sucrose than the bottom parts ever had. The development of the second-season suckers took place at the same time

as the top parts of the first-season cane. Could not the same conditions which make possible the higher concentration of sucrose in the top section of the first-season cane operate similarly in the case of the late suckers?

Secondly, we all know that in a field of cane each successive order of suckers is thicker and bigger than the previous ones. We explain this fact by assuming that the higher order avails itself of the materials elaborated by the previous orders of stalks in the stool and thereby gets an excellent start. May there not be some similar reasons why, under favorable conditions, each successive order should be capable of accumulating more sucrose than the ones previous? The scheme here proposed is not to be considered as final, but as something that should receive further study and thought.*

Differences in juice quality in the different parts of the same stalk: From a practical standpoint, the differences in the quality of the same stalk at different ages may be of even more significance than the difference between successive orders. How does a cane mature? Is the sucrose or glucose content the same in the different parts of the cane? How do seasonal influences or cultural treatments affect the various parts of the cane? With these thoughts in mind we harvested several lines of cane. At harvest we segregated the stalks of various orders and each stalk was divided into the following sections, working from the top downward:

(1) Non-millable top with leaves.
(2) Millable cane.

The millable cane was further divided into 4 sections:

(a) The green-leaf part.
(b) The top 4 feet of cane remaining after the removal of the green-leaf part.
(c) The extreme bottom 4 feet, i.e., 4 feet of cane directly above the ground.
(d) The section between b and c, hereafter called the middle section.

The green-leaf part is defined as that part of the cane where the attached leaves are still wholly or partly green. In actual practice the green-leaf part ended at a point where on removing the leafsheath no scar was left on the stalk. It is believed that since the green leaves are attached to this section only, this would also be the zone of most active sucrose accumulation. The results obtained appear to justify such belief.†

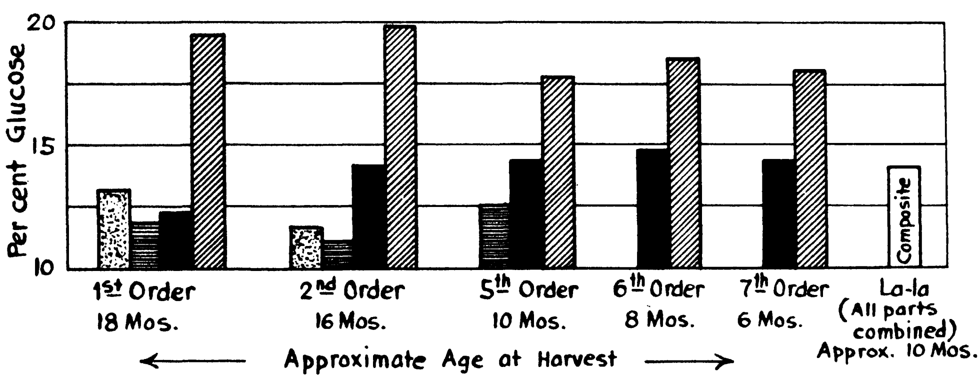
The cutting of cane according to the above scheme appears to have merit, especially for the purposes of fundamental study, over the general practice of cutting cane into equal sections working from the bottom upward. Let us consider the case of a sucker which is 8 months old and contains, say, only 4 feet of

* In comparing our results with those of workers in other countries one must remember that our crop is usually 20 to 22 months long and although we fertilize very heavily, the cane receives very little in the last year of growth. Our unique agriculture must of necessity give us different results.

† So far as we know, the sugar station at Coimbatore, India, was the first to suggest the value of separating the cane into green-leaf and dry-leaf sections for studying juice quality.

cane. In the more generally used practice we would be comparing the bottom of this young cane with the bottom of an old, say, 18-month cane. One can easily see that the comparison would hardly be valid, for the simple reason that the two sections did not grow at the same time. In the present scheme, this sucker would have only a top section (for we shall work from the top downward) and this would be compared with the top section of an old cane. There is great probability that both these sections were growing at the same time and were therefore equally influenced by environmental factors. Thus it happens that where the length of cane is less than 8 feet we have obtained only top and middle sections—and from our point of view this cane consists of no section comparable to the bottom section of a 12- or 14-foot cane. The data are presented in Table XII and Figs. 20, 20-A and 20-B.

In regard to sucrose per cent, we see at once that in all stalk orders there is materially little difference in the different sections of the dry-leaf part of the millable cane (i. e., the part of millable cane without the green-leaf section), but



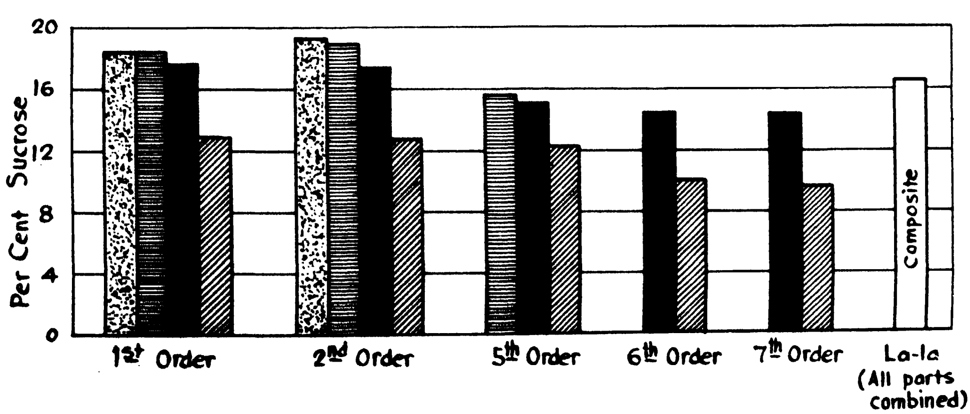


Fig. 20

Figs. 20, 20-A and 20-B. These three figures show that sucrose and glucose are more or less uniform throughout the length of the dry-leaf part of a cane. There is a sudden transition from the dry-leaf to the millable green-leaf part. The green-leaf section is therefore the only part of millable cane where active accumulation of sucrose is taking place. Even the top just below the millable green leaf has reached a state of maturity. It is also interesting to note that the point of maximum concentration of sucrose apparently moves from the bottom to the top as the field gets old. Actually, the bottom still remains the same while the top becomes richer in sucrose.

Note: In Figure 20-A and in subsequent figures "green leaves" and "dry leaves" should read "green leaf" and "dry leaf".

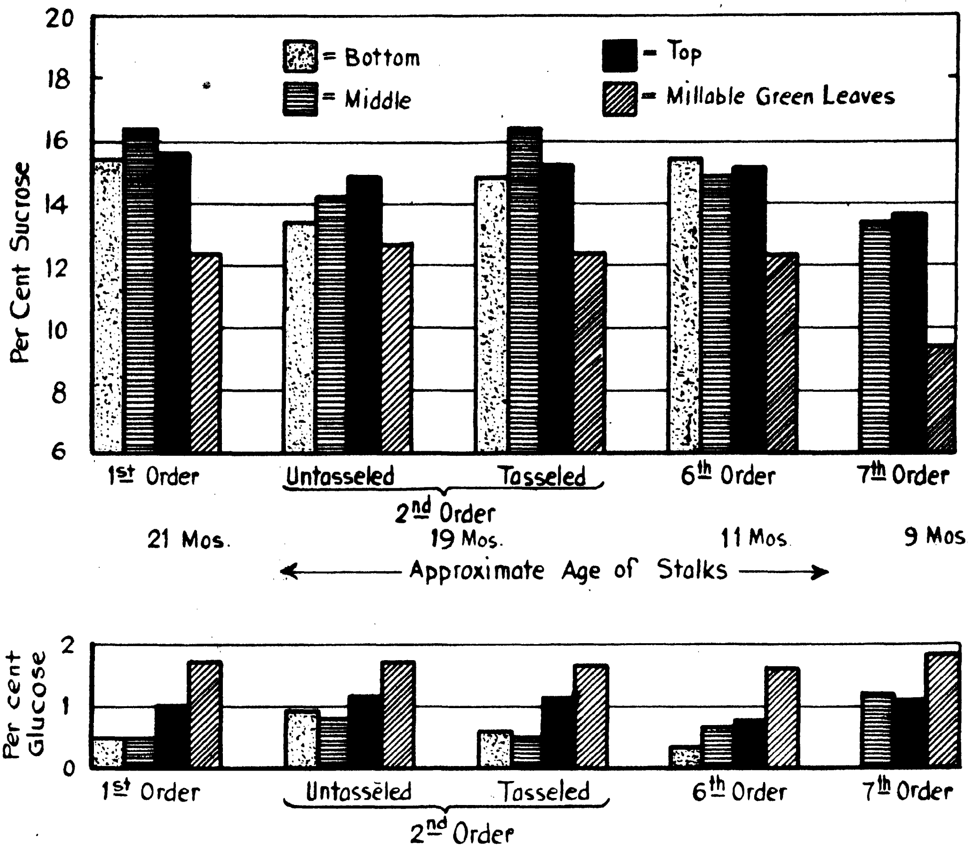


Fig. 20-A

(For legend, see Fig. 20.)

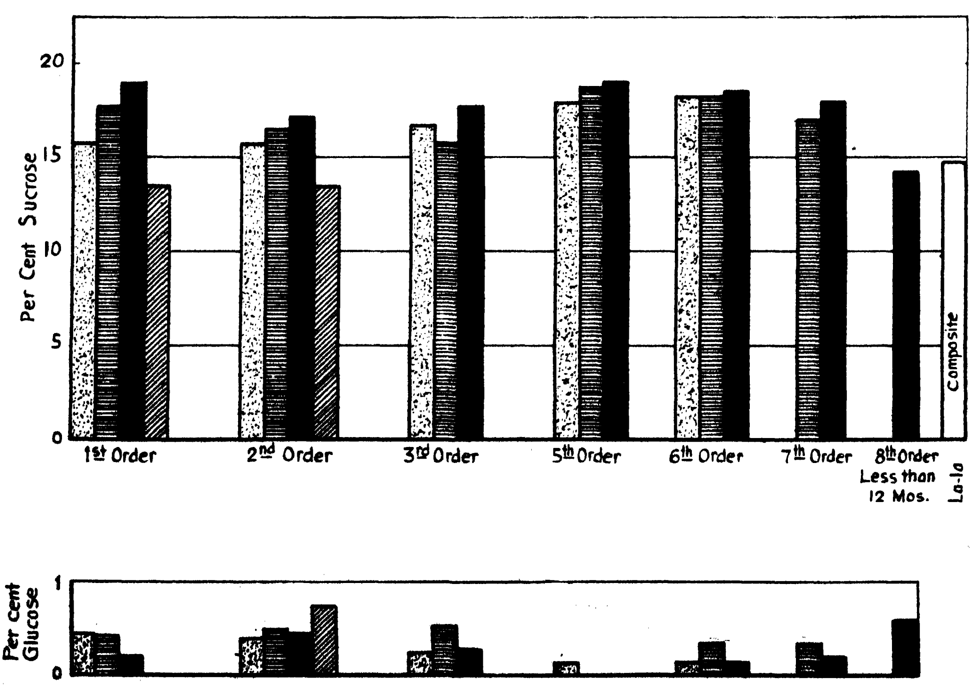
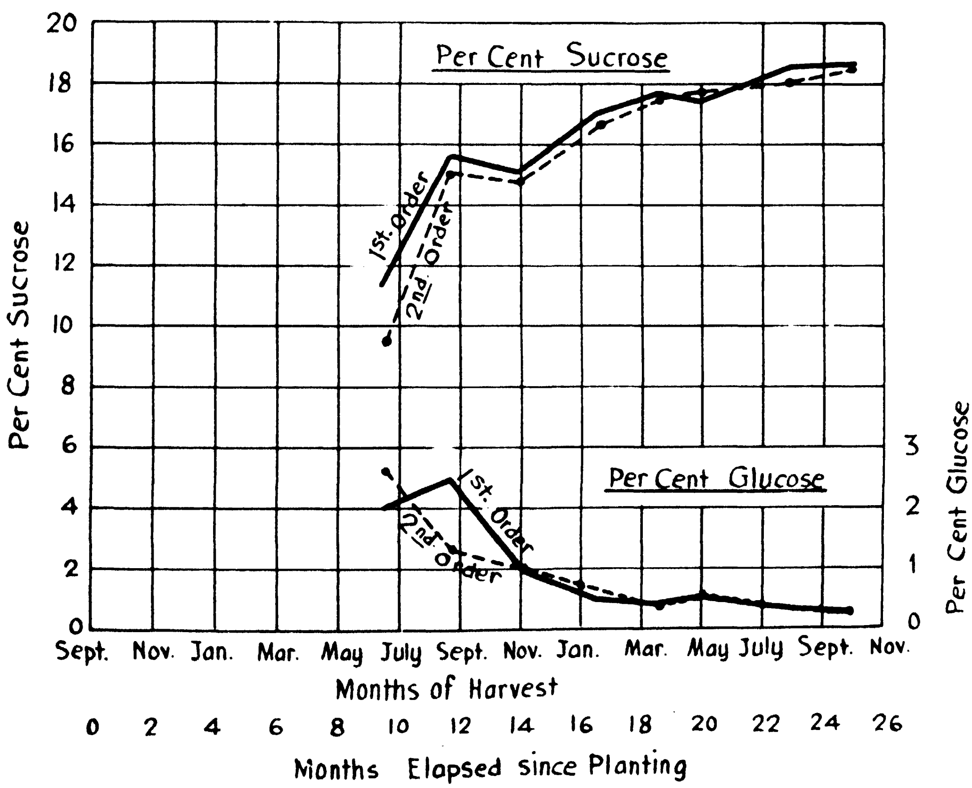


Fig. 20-B

(For legend, see Fig. 20.)

from there to the green-leaf part there is a sudden decline in sucrose content. In other words we may say that the green-leaf section is still in the process of gathering sucrose, while the dead-leaf part has reached a certain state of maturity. We do not imply that the level of sucrose in the dead-leaf part will not rise any further. In fact there are grounds for believing that it does rise to a small extent in young stalks, but what we do emphasize is this, that the green-leaf part is the one that is capable of the most advancement in sucrose; this is the part that is now growing and will be comparatively more susceptible to present environment and treatments than any other part.

The relative proportion of the green-leaf part to the dead-leaf section is therefore a matter of very great importance from a practical standpoint; for the average juice of a stalk is a composite of these two sections. The superiority of an old cane over a young sucker is undoubtedly due in a large measure to the fact that in young, vigorously growing suckers, the green-leaf part may constitute fully one-third or one-half of the whole millable stalk. In the old cane it may be, and generally is, about one-eighth, one-tenth or less of the whole stalk. Even if the sucrose content in the dead-leaf and green-leaf sections of the two canes were identical, we should find a great difference in the average juice quality of the two canes, much in favor of the older cane.



Percentage of sucrose and glucose in juice of stalks of various orders. (Cane planted September, 1931.)

Fig. 21. Similarly, as in March-planted cane, the quality of juice in this planting continues to improve to an age of 25 months.

One may therefore ask the question as to what actually happens when we withhold water from the maturing cane. We have seen that the dead-leaf section had reached a certain state of maturity long before harvest time and the accumulation of sucrose in that part was mostly influenced by conditions of environment and culture that are now past history. Could it not be that in ripening-off we are concentrating our efforts primarily on the green-leaf section? True, the withholding of water may drive off a small percentage of moisture from the cane, but probably the greatest thing it does is to stop new growth, and at the same time add more to the dead-leaf section by reducing the size of the green-leaf section.

Point of maximum sucrose content: When the field was harvested at 18 months of age, the maximum concentration of sucrose was still in the bottom section. Three months later the middle section appeared to have the maximum concentration in several orders of stalks; and another 5 months later, or at the age of 26 months, the maximum sucrose content appeared to be definitely located in the top section. This does not necessarily mean that the bottom section had deteriorated rapidly since the first harvest at 18 months. In fact our data show that the bottom part had remained practically still, but it was the top part which had come up considerably in sucrose.* Theoretically there is no reason why there should be a great deterioration of sucrose in the bottom part of a healthy stalk of cane. If sucrose must break down into reducing sugars to supply the respiratory needs of the bottom joints this demand can be only very small.† This improvement in the top part may be due to environmental conditions of weather or culture or to some physiological reasons. We shall take up this point in discussing the detailed joint-to-joint analyses.

Glucose in the various parts: As in the case of sucrose the concentration of glucose also changes suddenly as we move from the dead-leaf to the green-leaf section. This sudden increase in the amount of glucose in the green-leaf section again points to the conclusion that this is the part of the cane where active processes are still going on.

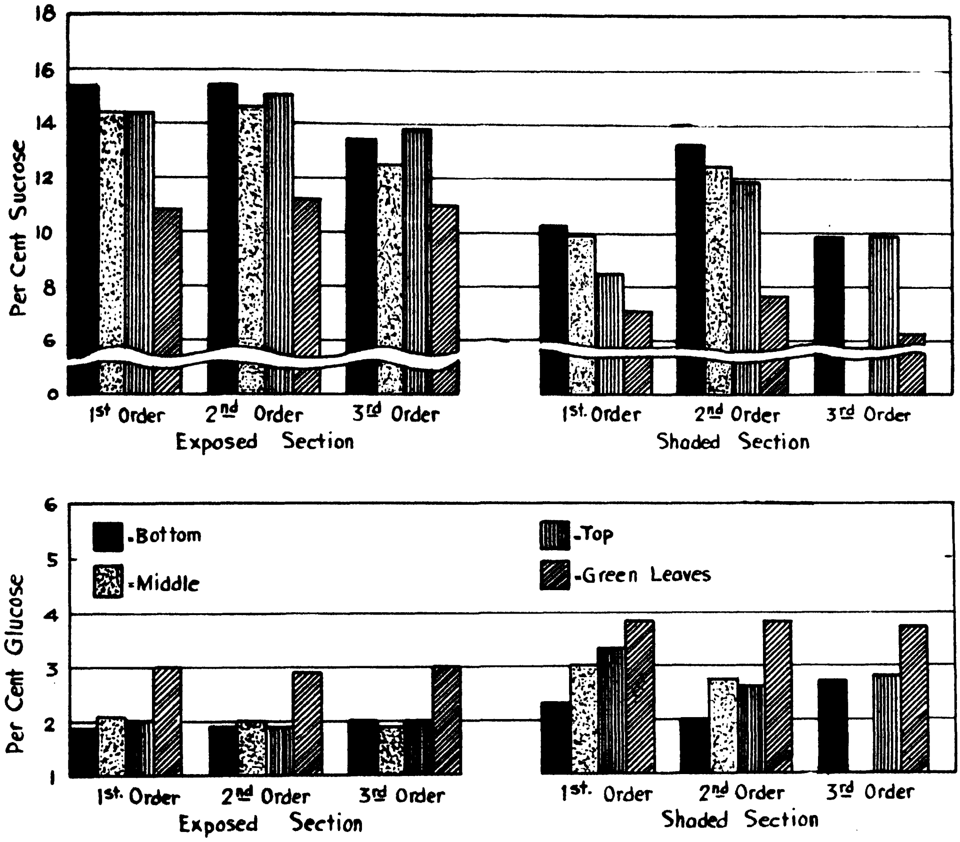
September Planting:

Juice quality in the first- and second-order stalks: In Table XIII and Fig. 21 we see that here also the per cent of sucrose rises steadily to 25 months. Here also there is essentially no difference between the quality of the first- and the second-order stalks after the first few months.

Exposed vs. shaded plants: Fig. 22 shows the juice quality of exposed and shaded plants in the harvest at 15 months. The other harvests also show similar differences. The exposed plants have generally a higher percentage

* The harvest at 18 months was from an outside line and therefore should not be compared with the results of the two later harvests which were from inside lines only. Our detailed juice analysis data shown elsewhere in this paper fully support the statement just made.

† In this connection it may be of some interest to study the concentration of the enzyme invertase in different parts of 18-month-old stalks. Dr. Constance E. Hartt of this Experiment Station who is responsible for these determinations finds that in 18-month-old cane the invertase concentration drops from a level of about 20.0 (expressed in cc's of $N/20$ $KMnO_4$) in the growing point to 8.9 in the green-leaf part and down to only 1.3 in the bottom joints. In other words the invertase activity is so low in the bottom part that we need fear no great breakdown of sucrose—barring mechanical or other injury leading to active deterioration of tissue.



Comparing the juice quality of exposed and shaded sections. Harvested November 30, 1932. Age about 15 months.

Fig. 22. Fig. 16 showed that the shaded plants always had less weight of cane than the exposed plants. This figure shows that the same applies to sucrose concentration in the entire cane including millable green-leaf part.

of sucrose than the shaded plants—particularly the first-order stalks which were the ones to suffer most from shading effects. The shaded plants have also a high percentage of glucose—not as an indication of greater vigor but probably of a slower rate of utilization. In this figure we see that the differences between shaded and exposed plants are not confined to one section only of the stalk, but throughout the whole length of the stalk. There are areas in these Islands subject to similar shading in the mornings. It is easy to see why these areas will not be equal either in tonnage or in quality to areas under continuous exposure.

X. Joint-to-Joint Analysis of Cane Stalks

We have seen in Fig. 20 that the sucrose per cent of juice is more or less uniform in the bottom, middle, and top sections of the dry-leaf part of the plant and that there is a sudden drop as we go from the dead-leaf to the green-leaf section. We are then interested in knowing whether the percentage of sucrose within the dry-leaf section is uniform throughout from joint to joint. We have made a large number of joint-to-joint analyses of stalks at different ages of which a few typical

examples are shown in the following Figs.: 23, 23-A, 23-B, and 23-C.* Let us first take a typical first-order stalk 26 months of age which has not tasseled (Fig. 23). The lowest joint has a Brix of 20°, and thereafter the Brix varies between 19° to 21° joint after joint until the fifty-fifth joint or so. In the succeeding top joints the Brix goes up to 23°, coming down again to 19° where the millable green-leaf part starts. From this point there is a sharp drop in Brix in successive joints until a reading of 11° is reached in the first non-millable joint of the stalk. We can simplify the picture by saying that all joints from the first to the seventy-fifth

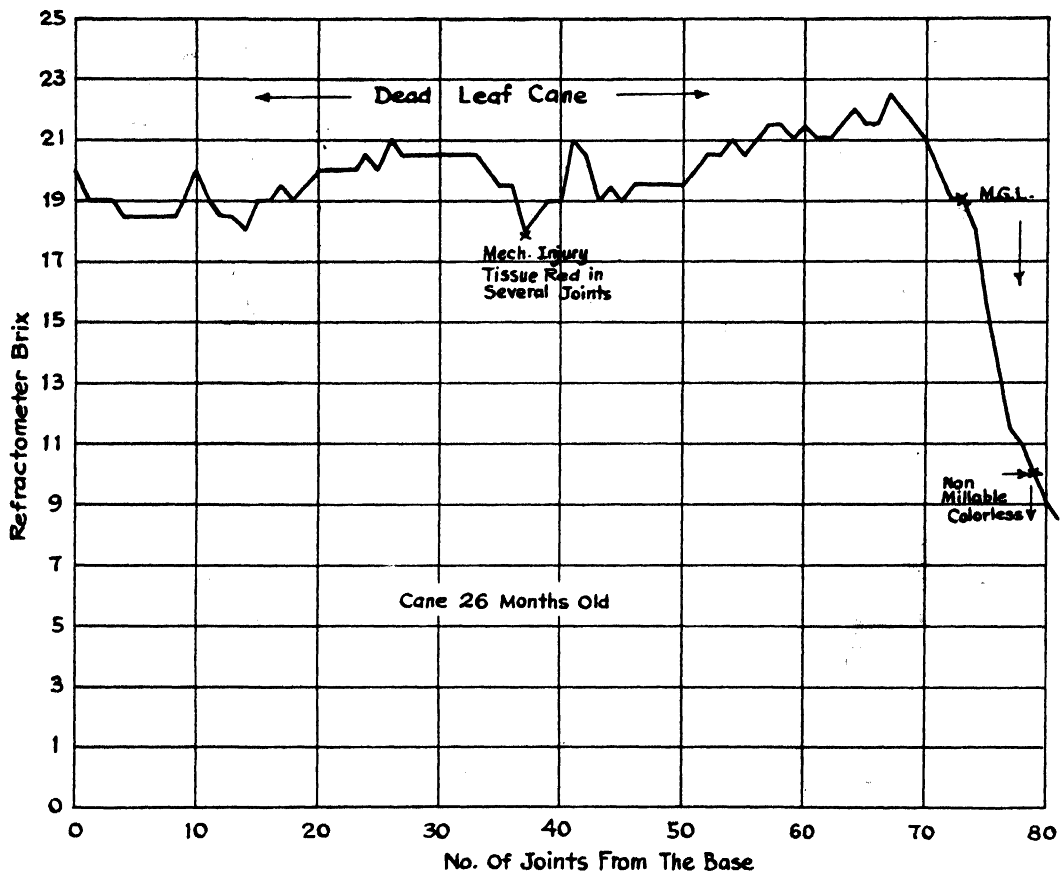
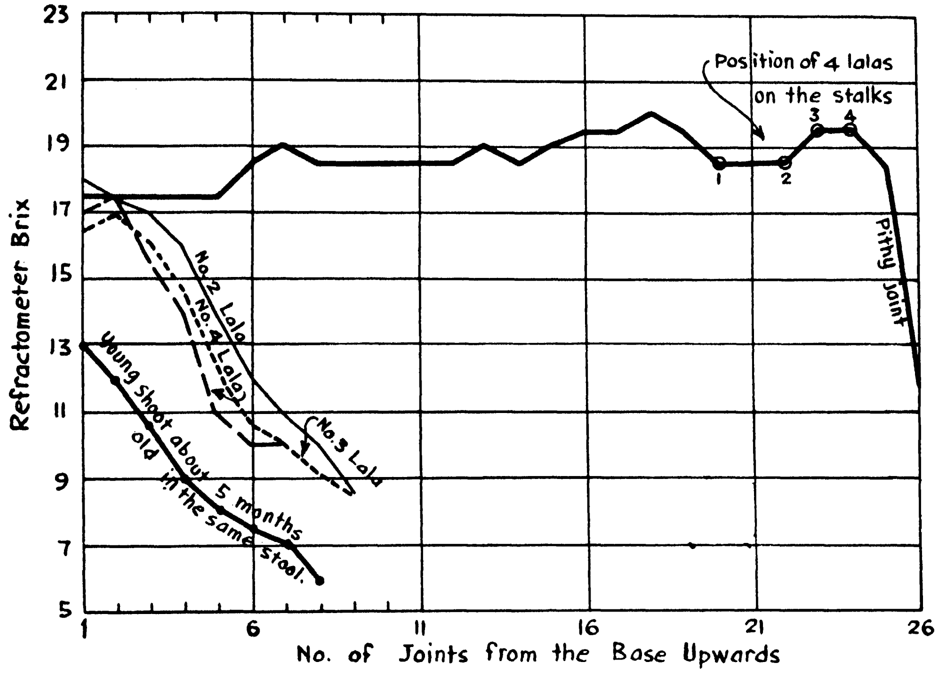


Fig. 23

In Figs. 23, 23-A, 23-B, 23-C, and 23-D the joint-to-joint analysis of Brix confirms our previous statement that the millable green-leaf part is the only part which is actively gathering sucrose. The level of Brix is more or less uniform from joint to joint throughout the entire length of the dry-leaf part. The level drops fast joint after joint as we reach the millable green-leaf part. It seems reasonable to assume that the dry-leaf part is more or less beyond improvement in the later stages of the crop. It is with the millable green-leaf part that we must be concerned in our effort to increase the average quality of juice. The ratio of the millable green-leaf to the dry-leaf part is thus an important factor in determining average juice quality of the whole stalk. The tasseled stalks, excepting the pithy joints, are uniform throughout in Brix.

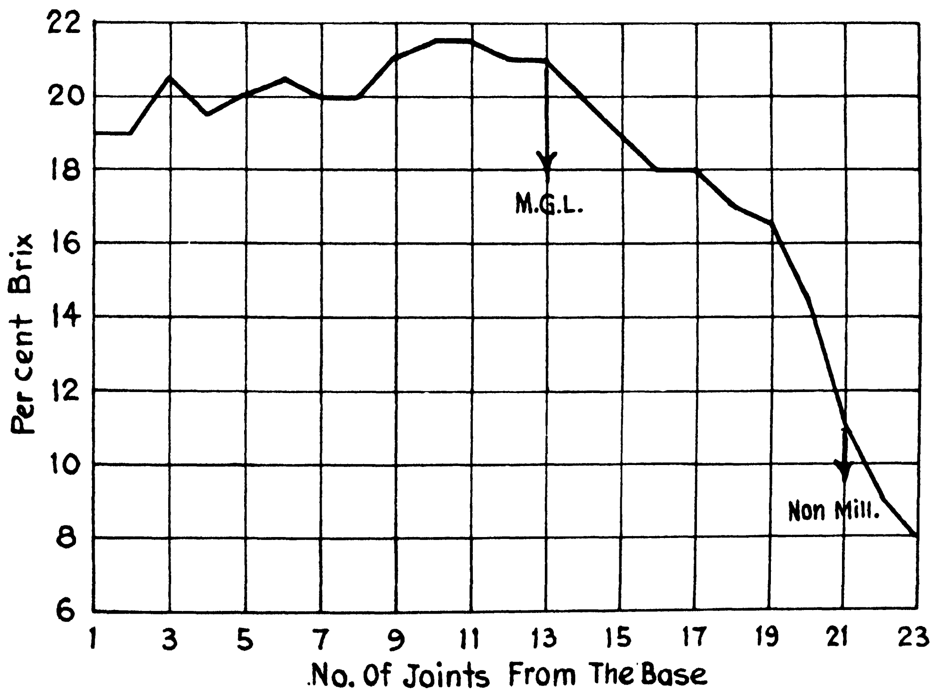
* In the joint-to-joint analyses, Brix readings were obtained for each joint, using a hand refractometer manufactured by Carl Zeiss, Inc.—the juice being extracted with a puncturing needle made by the same firm. This needle makes a clean puncture and extracts two or three large drops of juice at a time. The difference between duplicate readings from the same joint is seldom more than half a point. Needless to say the punctures should be made in the same relative position on each joint.



Sixth-order stalk—tasseled—with lalas.
Stalk—16 months old.
Lalas—about 4-5 months old.

Fig. 23-A

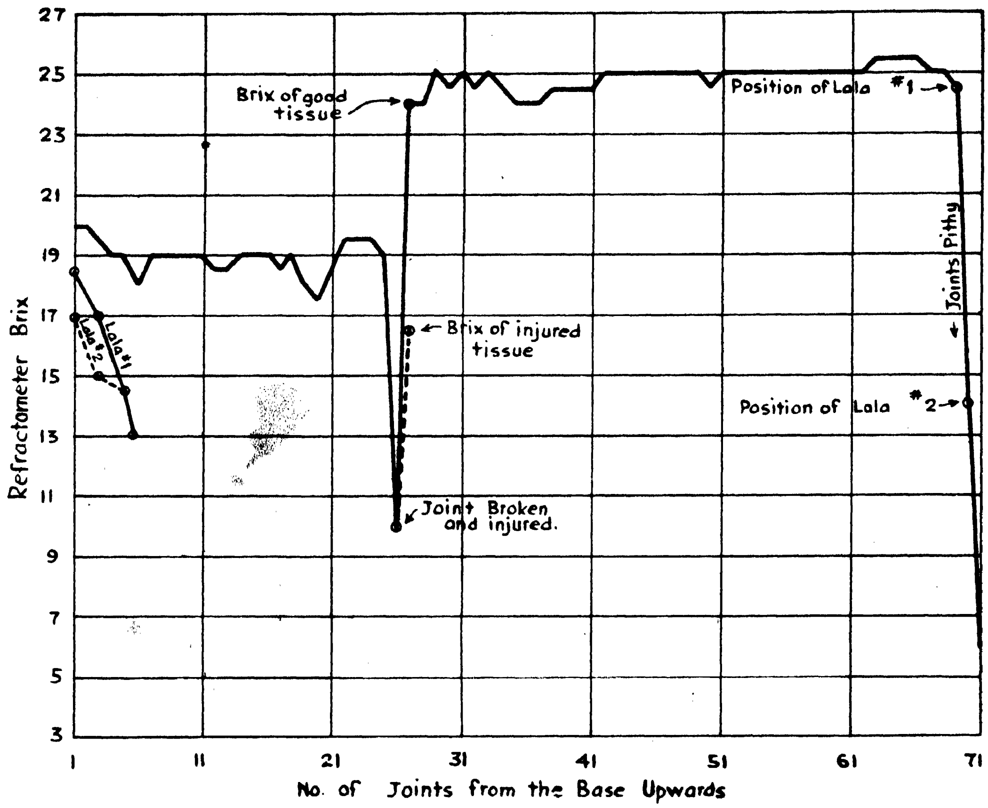
(For legend, see Fig. 23.)



Joint-to-joint analysis of refractometer Brix of a young sucker less than a year old.

Fig. 23-B

(For legend, see Fig. 23.)



Joint-to-joint Brix of a primary stalk 26 months old (Stalk tasseled 6 months before harvest).

Fig. 23-C

(For legend, see Fig. 23.)

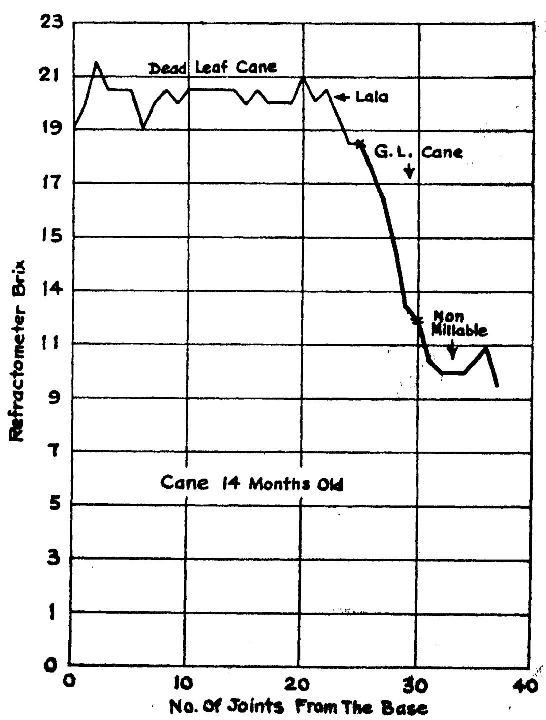


Fig. 23-D

(For legend, see Fig. 23.)

are on one level, the millable green-leaf on another and much lower level, and the non-millable on another still lower level. There is an abrupt change in the curve as soon as we come to the green-leaf part, as was so clearly brought out in the previous analyses of different sections of the stalk. We may therefore state that the entire dry-leaf part has reached about the same state of maturity while the green-leaf part is still immature and has yet to accumulate a great deal of sucrose.

Fig. 23 shows that the top joints just below the millable green-leaf part have the highest concentration of Brix. We have encountered this higher quality of the top joints previously in our sectional analysis of stalks and we find it now in our joint-to-joint analysis of big cane. We therefore feel that it is a significant fact to which attention must be drawn. Does the greater sucrose concentration in these top parts indicate that as the cane grows old, and vegetative vigor decreases, a relatively larger percentage of the sucrose elaborated is stored without being utilized in the formation of new matter? We would then picture the accumulation of sucrose joint by joint to be accomplished in the following manner: In the early stages of the crop there is a rapid expansion of vegetative growth. Each stalk is growing to an adult stage and also contributing to the support of others that are coming into existence. The expenditure of sucrose for building new tissue matter must be great at this time, relative to the assimilation of sucrose, and as a result we may expect less storage of unused sucrose. As the crop gets old and vegetative growth slows down, a large percentage of the sucrose elaborated may be stored, not being required for new growth. Therefore in the latter stages of the crop where growth is at a very low point due, among other causes, to the withholding of nitrogen, the sucrose storage in each joint must reach a very high level. In other words rate of utilization, rather than rate of formation of sucrose, governs its concentration in each joint. In the latter stages rate of formation may be low, but the rate of utilization may be relatively lower, with the result that net gain may be greater.

However, it must be borne in mind that as practical sugar planters we are not so much concerned with the rate of sucrose storage and its high concentration in the top joints, as we are with the total quantity of sugar (we should say total profit) that the stalk may yield. Rate of cane formation may then be the more dominant consideration. We shall discuss this point more fully in connection with our analysis of nitrogen fertilization.

We have definite evidence from a current experiment that the joint that is now elongating and is situated in the non-millable section goes through the green-leaf and reaches the dry-leaf stage in the short time of about 3 to 4 months. This means that the joints that now have practically no sugar will have reached a state of maturity with about 18° to 20° Brix in the course of the next 3 to 4 months. The accumulation of sucrose in the joints newly laid down must therefore be very rapid.

Let us next take the case of a sixth-order stalk harvested at the same time as the first-order stalk just discussed (Fig. 23-A). This sixth-order stalk was, however, only 15 to 16 months old at the time of harvest, having sprouted several months later than the first-order stalk. This stalk had tasseled so we have no green-leaf part, but here also the Brix level is practically uniform throughout the

entire length of the stalk. The Brix falls very rapidly as soon as we come to the terminal joints which are pithy as a result of tasseling.

Now take the case of a much younger stalk of cane—one that is less than 12 months old and has only 5½ pounds of millable cane and about 23 internodes (Fig. 23-B). Here again the entire dry-leaf section has about the same level of concentration, the Brix falling off rapidly as we come to the green-leaf section. It is thus stating a fact with no exaggeration to say that even a 6-month-old cane is more or less mature in the *dry-leaf part.*

Here is a unique case of a stalk that had been injured some time previously and was maintaining a growing and big top by the slender connection of the rind and a little tissue only (Fig. 23-C). This was a first-order tasseled stalk, 26 months old. The curve shows that in this stalk the lowest joint has a Brix of 20° and the figure remains between 19° and 20° for the next 20 joints; there is then a sharp decline in the course of one joint to a Brix of 10° (the tissue in the exposed part of the broken joint had deteriorated due to attacks of fungi and other organisms). In the very next joint the Brix rises to 24° and from then on a level of 24° to 25° Brix is maintained to the sixty-eighth joint, when the Brix falls to almost nothing in the course of another two joints. These last two joints were pithy as the after effect of tasseling. One is at once struck by the tremendous gradient of sucrose concentration that can exist in adjoining joints, and even in the adjoining tissues of the same joint; for in the joint (No. 27) next to the broken joint with 10° Brix we have the interesting fact that on one side of the internode where there is some red and deteriorated tissue the Brix is only 16°, while on the other side where the tissue is sound the Brix is 24°.

XI. Ripening or Maturity in Cane

No aspect of cane culture is more beset with confusion than ripening. What do we mean after all, by such terms as mature or ripe cane? In fruits or other crops there is no doubt what constitutes maturity, but in sugar cane there is unfortunately no such apparent and convenient index of ripeness. Maturity cannot simply be an arbitrary concentration of sucrose, for we realize that in different varieties and in different localities what are considered ripe canes will have widely differing sucrose contents. We also realize that occasionally heavy rainfall prior to harvesting a "dried-off" cane may dilute the juice of a so-called "ripe cane" and lower the concentration of sucrose without in any way lowering the total quantity of sugar in the stalk. Similarly an arbitrary percentage of glucose may not serve as an index of ripening. It has been suggested that purity or a simple sucrose-glucose ratio will provide a better index of maturity. It appears to us that no arbitrarily set constant will be satisfactory under all circumstances. Maturity would appear to be a relative term. We would like to define it as the accumulation by a variety of the maximum amount of sucrose under the conditions of culture and environment—in the process the green-leaf part of the stalk to gradually become smaller and smaller and be finally reduced to a negligible quantity. Ripening would thus be a process of lengthening the dry-leaf part and simultaneously shortening the green-leaf part. There is no doubt that this is about

all we do in our various efforts at "ripening-off," such as cutting off water, withholding nitrogen, etc.

Much of this confusion would be eliminated if we considered ripening as a continuous process and not as a last-minute effort of the plant which has grown vegetatively for 18 months and is building up sucrose in the stalk in the last few months before harvest. As each joint is laid, it accumulates sucrose, matures, and by the time it has reached the dry-leaf status it is already more or less mature. Once this conception of ripening, based as it is upon the facts of the situation, is realized by all of us who grow cane, we shall be less inclined to concentrate our efforts on ripening the cane in the last few months before harvesting, but so plan our agricultural policy that the cane will have ample opportunity to grow well and come to maturity in the natural course of events.

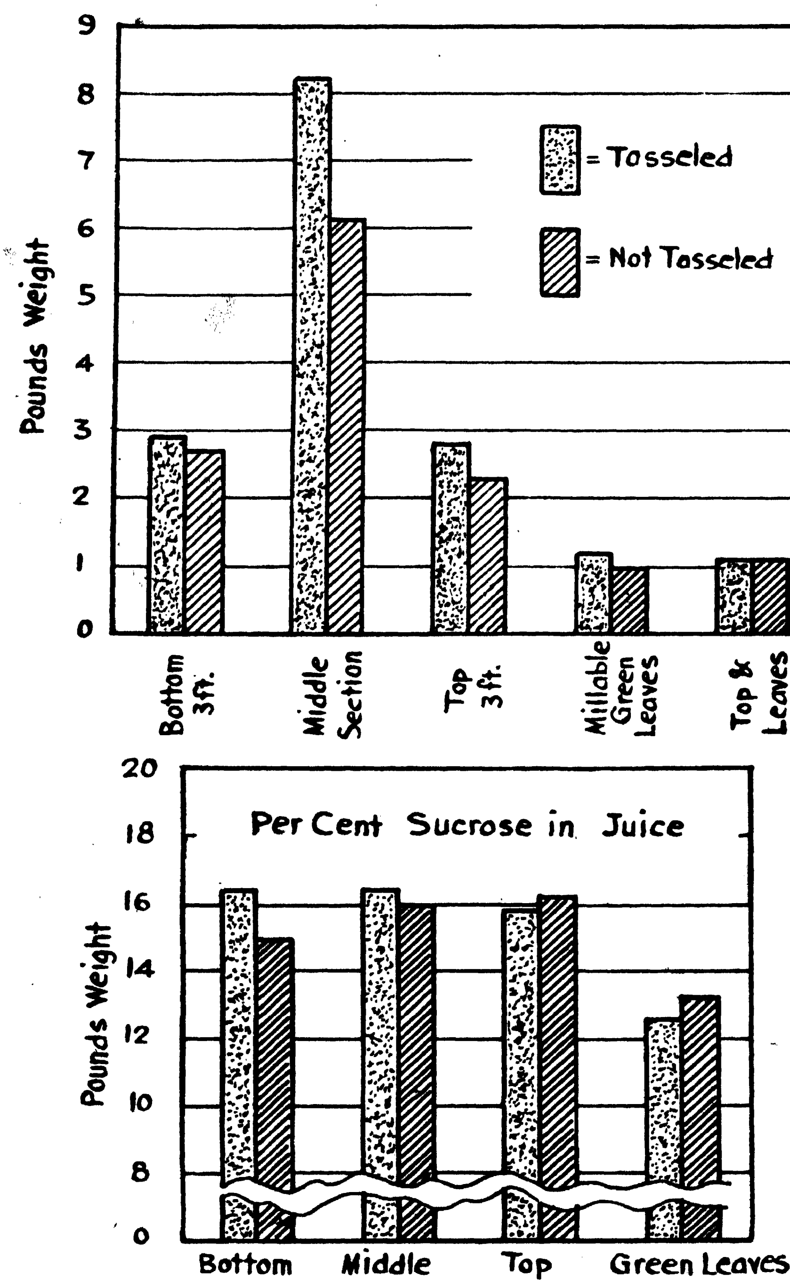
Our present studies clearly indicate that there is little possibility for the joint which has been laid 18 to 20 months ago to be still carrying on the process of sucrose accumulation. These joints may then be considered relatively fixed in sucrose per cent; the only joints on which we need concentrate our attention will be the millable green-leaf part. This being the case, could we not simplify our pre-harvest examination of a cane field by measuring the length or size of the green-leaf part of the millable stick instead of running detailed juice analysis of the whole stalk?

XII. Rate of Sucrose Accumulation at Various Ages

In a note appearing in *The Hawaiian Planters' Record*, Vol. XXXVII, p. 92, 1933, the writer showed that the rate of sucrose accumulation in a crop was highest between 9 and 12 months of age. Figs. 17 and 21 fully support our previous data. In both the March and September plantings, the rate is found to be highest between 9 and 12 months of age. This rate of sucrose accumulation is no doubt intimately related to the rate of cane formation at various ages and determined by the relative proportions of dry-leaf and green-leaf parts.

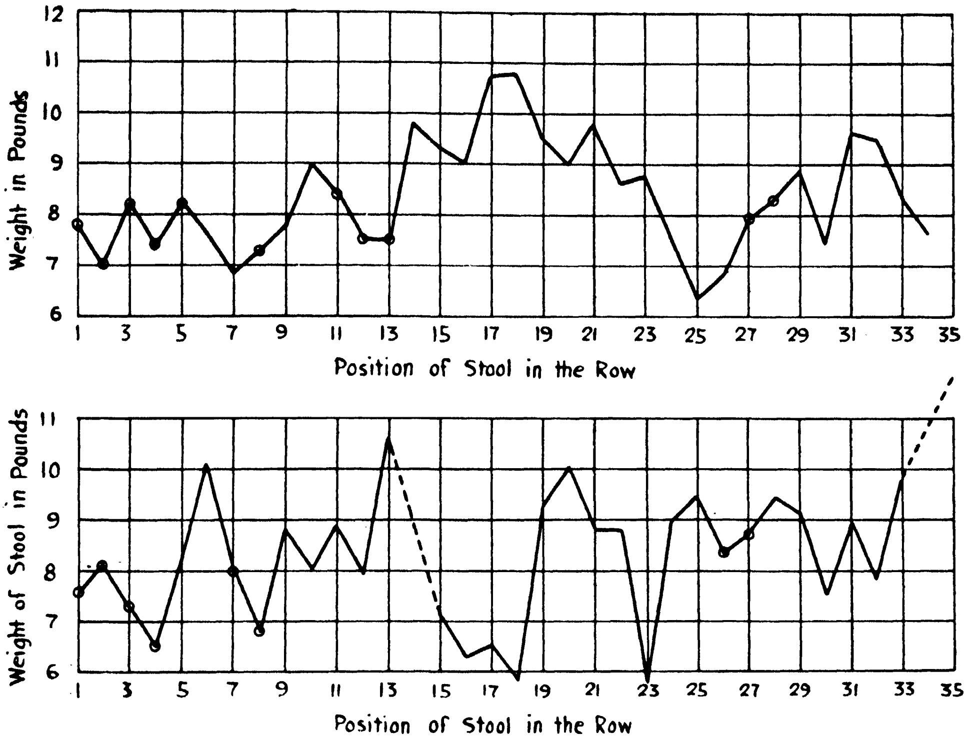
XIII. Tasseling Effect

A great deal of discussion still goes on as to the how and why of tassels, and controversy still rages as to their after effects. The data that we shall present do not answer the question why some canes tassel and others apparently very similar do not, but they do tell us what happens to the concentration of sucrose in the stalks after they have tasseled. In one line of March-planted cane, we segregated the second-order stalks according to whether or not they had tasseled. To further strengthen the comparison, we took only those stalks which were in the same stool, *i. e.*, growing from the same clump. These stalks which had been growing so intimately together may be believed to be as uniform as it is possible under field conditions; but when we analyzed the stalks we found that the tasseled stalks were on the average heavier than the untasseled stalks in the bottom, middle, top, and green-leaf sections (Table XIV and Fig. 24). With regard to sucrose, the tasseled stalks had a higher percentage in the bottom and middle sections, but slightly lower in the top and green-leaf sections (this lower concentration may



Comparing the weight and sucrose content of various parts of tasseled and untasseled stalks.

Fig. 24. The tasseled stalks are here seen to be heavier and richer in sucrose than the untasseled stalks from the same stool. This might suggest that it is only the more vigorous stalks that tassel, but quite a different picture is given by Fig. 25.



Showing the weight of successive first-order stalks in two rows of cane. (September planting.)

Fig. 25. The weights of successive first-order stalks in two lines of cane are shown. Those that tasseled are marked by circles. Tasseling does not seem to be confined either to the most- or to the least-vigorous stalks but to stalks of about average weight.

indicate that some sucrose was used by the tassel). If this evidence stood alone we might have concluded that generally the stalks that were more vigorous were the ones that tasseled, but quite a different picture is presented by the cane in the September planting. Fig. 25 shows the weight of the first-order stalks of two lines of cane and their respective positions in the row. The figure also shows which of these stalks tasseled and which did not. We observe immediately that tasseling is scattered here and there in apparent confusion. Tasseled stalks seem to be more concentrated toward one end of the row than the other. The end having more tassels happens to be the exposed end, that is, there was no cane beyond this end, but the point we started to make is that tasseling seems to be confined not to the most vigorous stalks, nor to the very weak stalks, but to stalks that are of average weight. In other words the more vigorous stalks do not necessarily tassel. Thus tasseling still remains a mystery. The fact that neither the extremely weak nor the extremely vigorous stalks tassel may lead us to the assumption that tasseling may be conditioned by a balance of factors within the plant—factors of which we know nothing for certain.

Effect on juices: The joint-to-joint analysis of tasseled stalks produced previously (Figs. 23-A and 23-C) shows that there is no evidence of the tasseling stalks going back in juice quality so long as the top has not started to die and degenerate. If we eliminate the one or two joints with pithy tissue, then we shall

find a tasseled stalk to be remarkably uniform in sucrose throughout its entire length. Furthermore, in such a stalk with no green-leaf part, the average sucrose concentration should be higher than an untasseled stalk which has a green-leaf part. However, it goes without saying that if we had a large number of pithy joints included in the stalk we should have an entirely different picture, for the pithy joints appear from our data to have very little sucrose.

We must realize, however, that an untasseled stalk which kept on growing may have more total sugar than a tasseled stalk, because of greater weight of cane.

XIV. Lalas

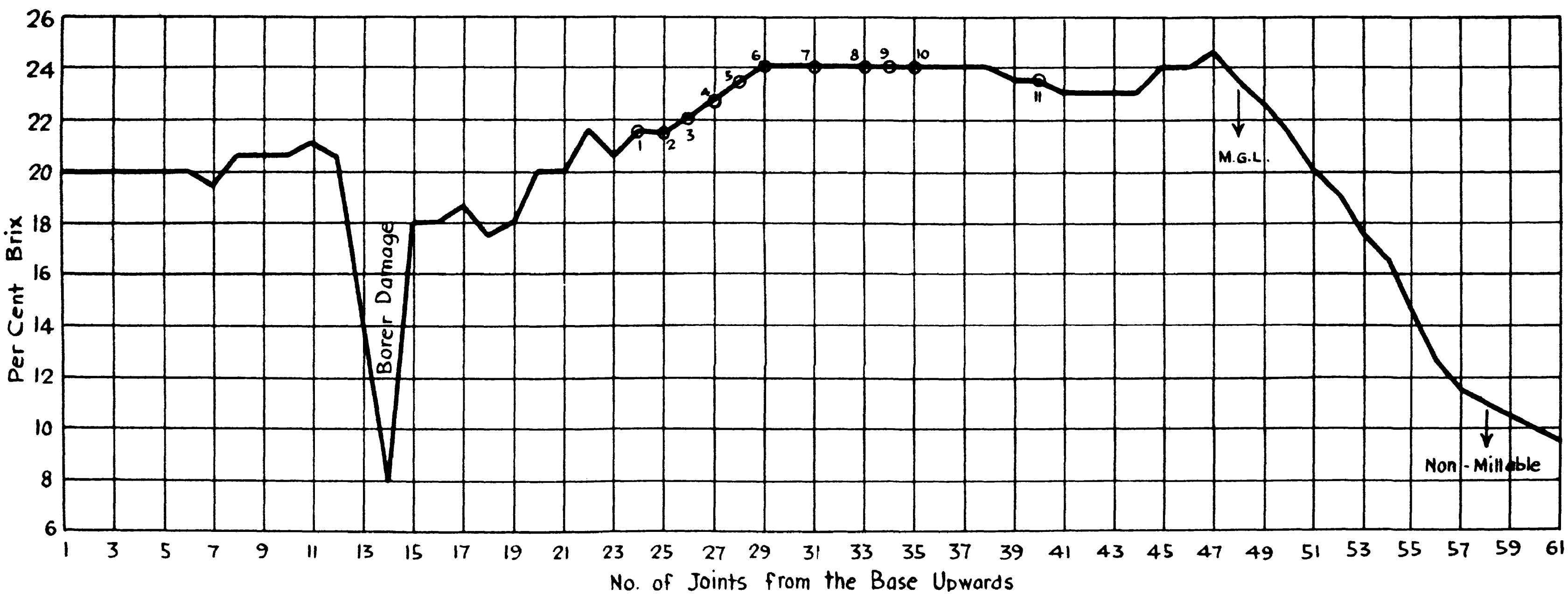
Lalas are side shoots that germinate from a dormant eye on a growing cane. The lalas draw nutrition only through the mother stalk and are not rooted in the soil like late suckers.

The lalas are generally considered to be an evil even though a necessary one. It is generally believed that lalas withdraw sucrose from the parent stalk while they themselves do not add much to the crop. Our data clearly show that not only are lalas not harmful (under the conditions of the experiment at least) but they have also more sugar than the suckers of equal age. Previously (Fig. 20) we have seen that even the small lalas that would not generally be harvested in the field had a sucrose concentration more approaching the parent stalk on which they were growing than the suckers with which the lalas were comparable in age. Fig. 23-A shows a joint-to-joint analysis of some lalas growing on a sixth-order stalk and also an analysis of a young sucker growing in the soil in the same stool. The lalas are on a much higher level than the sucker, but the Brix curves of both are of similar nature. Fig. 26 shows another extreme case of lala-ing in a big cane. This stalk had in all 11 lalas coming out at the internodes marked, but we fail to see any evidence of the deterioration of juices in any of these joints. If anything, the joints bearing the lalas had the highest sucrose content.

Fig. 27 shows the joint-to-joint analysis of that part of the mother stalk where the lalas were growing and the analysis of 4 millable lalas. There is very little evidence to say that the mother stalk had suffered appreciably from supporting these millable lalas. The analysis of the lalas proves of extreme interest. The nature of the Brix curve is the same as we have met before in suckers, but the level of concentration is very high for cane of such age and vigor. Even in the green-leaf parts the Brix is as high as 20°. Is this merely a result of the then growing conditions or does this high level suggest that the lalas have a greater capacity for sucrose accumulation because they are deriving some benefit from their intimate association with the big canes? Note again the great variation in the 4 lalas growing from adjacent joints of one cane.

XV. Influence of Borer and Mechanical Injury on Quality

The joint-to-joint analysis of stalks, that has been presented previously shows how badly the quality of a joint can be affected by borers or mechanical injury. In Fig. 23-C the Brix drops from 20° to 8° in going from one joint to another (in another extreme case, not reported in this paper, the Brix dropped to 2° in joints injured by borers). In other words one such poor joint pulls down the average



Joint-to-joint analysis of a first-season cane which had sent out a large number of lalas. The lalas are numbered and their position indicated.

Fig. 26. This first-season cane had 11 lalas on it when harvested. The qualities of the joints to which the lalas were attached are shown. There does not appear to be any deterioration of juices in the joints carrying the lalas. On the contrary these joints are the highest in Brix.

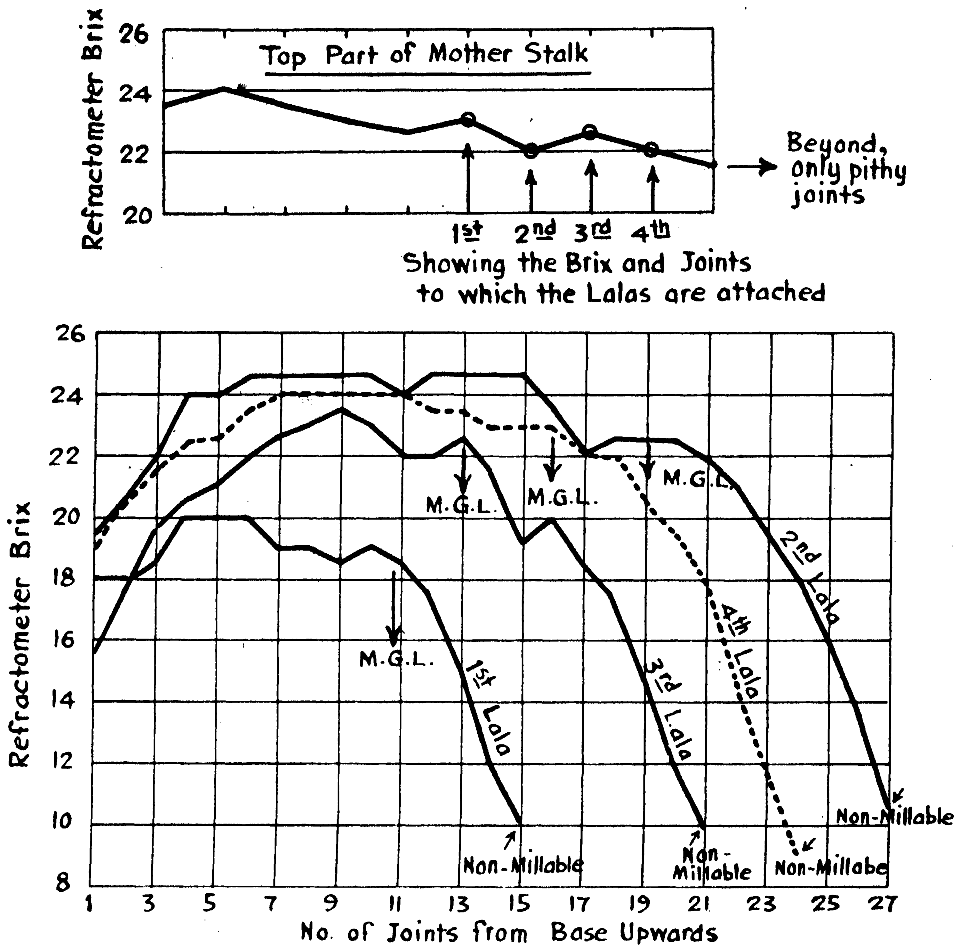


Fig. 27. Showing the joint-to-joint quality of four lalas growing from adjacent nodes of a first-season cane. These millable lalas growing from adjacent joints of a single stalk show remarkable variations in Brix content. The curve of Brix concentration from joint to joint is, however, of the same nature as shown previously with suckers. Note the high values obtained in the green-leaf parts.

for 12 or more joints by one whole point of sucrose on the basis of equal weight of juice. If we had 2 or 3 such joints in a cane, we might expect the average Brix for a whole big stalk to be lowered by one point.

XVI. Second-Season Application of Nitrogen

In the last few years there has been a marked tendency on the part of the industry to apply the last application of nitrogen at least 10 to 12 months prior to harvesting. In extreme cases this interval between the last application of nitrogen and harvest has been even greater. It has been argued that by so doing we are likely to get better juices. It is not our purpose to criticize this trend. All of us know that this policy has been an improvement on the past, but we want to raise the question whether or not the time has not come to re-examine the whole subject. In striving for quality are we sacrificing cane tonnage and sugar? Is it not possible to combine the advantages of quality and quantity by a different procedure?

These questions are being raised as a result of observations and some evidence tending to show that by stopping nitrogen applications so early in the life of the

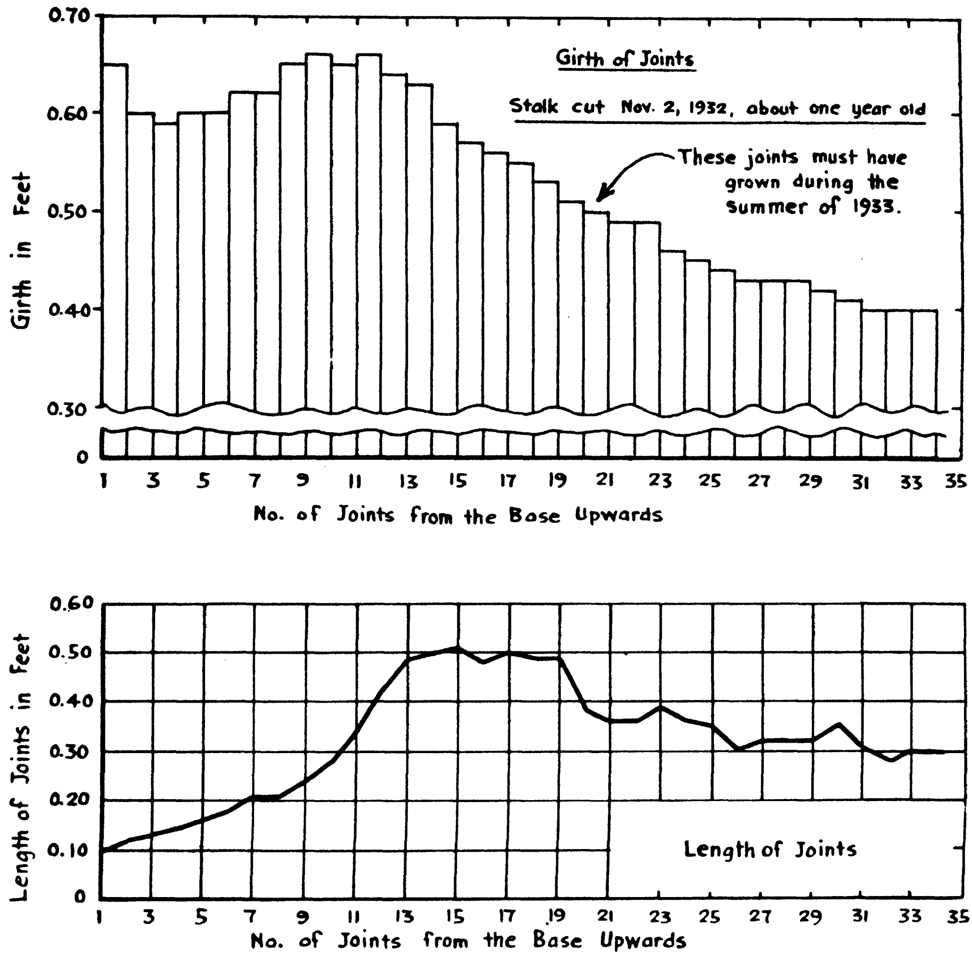


Fig. 28. The girth and length of each successive joint of a second-season stalk (sixth order) are here shown. The decrease in length and girth during the summer months is believed to be due to deficiency of plant food, particularly nitrogen.

crop we are not only starving the big cane, and increasing its chances of deterioration, but we are also depriving the second-season cane of much needed nourishment. We have remarked when discussing the rapid mortality after tasseling of the March-planted cane, that lack of vigor induced by lack of nitrogen might have been the contributory cause. Some measurements taken on second-season suckers appear to indicate the same lack of vigor and nitrogen deficiency. When these suckers came out, the joints were long and thick, but soon afterwards the joints started to shorten and grow less in girth, the tops became smaller, even though the stalks were going through the summer months. Fig. 28 will show the girth and length of each successive joint of a second-season stalk. From the time this one sprouted there had been applied only one application of nitrogen, the last one called for in our plan. Analysis of total nitrogen in second-season and first-season stalks (Table XV, Fig. 29) shows that the second-season stalks had actually much less nitrogen than the first-season cane. Thus the second-season canes which at times, numbered about 20 per cent of the total stalks harvested were left without nourishment; whereas, with more timely fertilization these might have contributed more substantially toward the total crop. It is interesting to speculate on what might

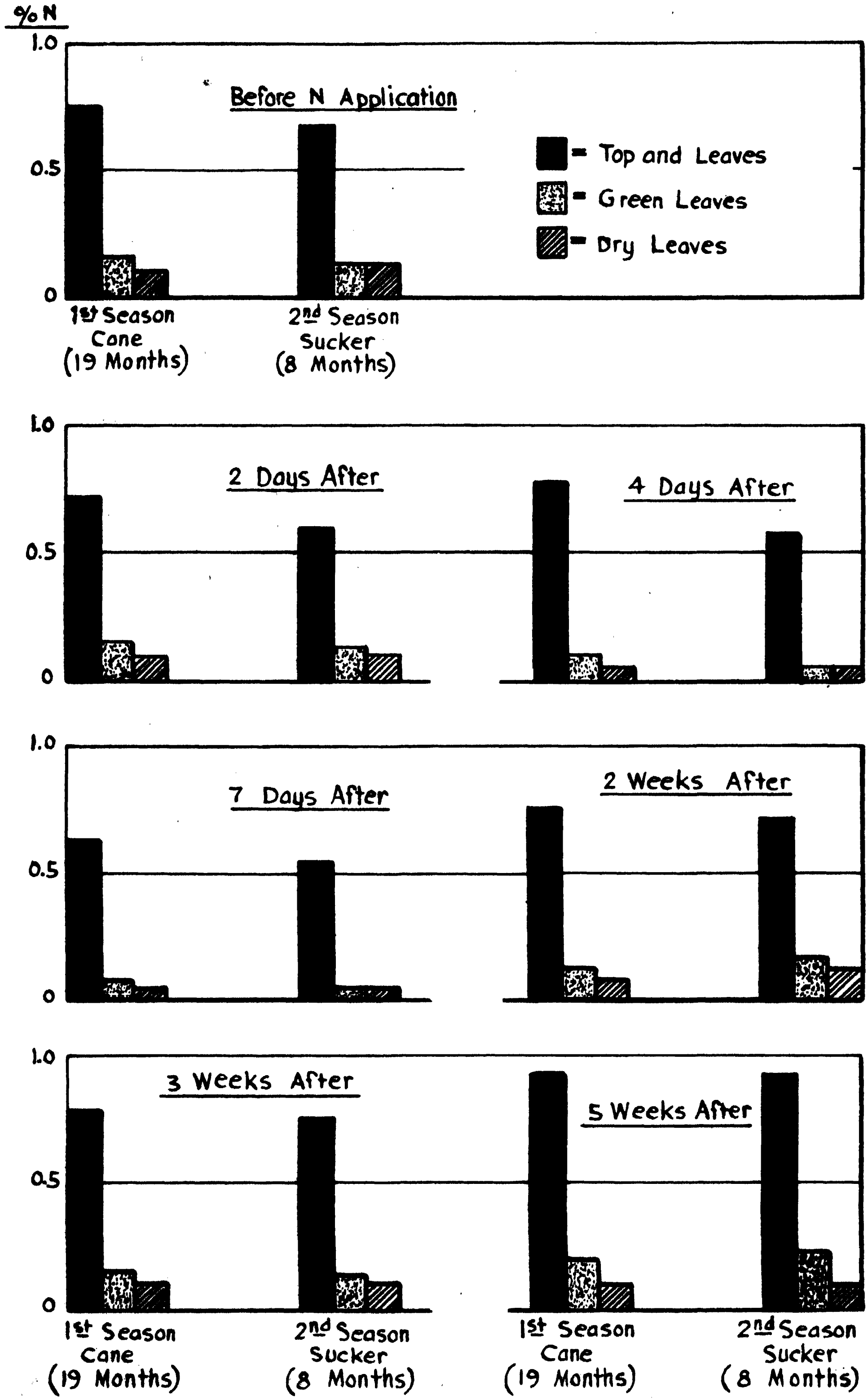


Fig. 29. Showing percentage of total nitrogen on dry basis in the different parts of first- and second-season cane. The young second-season suckers are seen to have less nitrogen in their composition than the old first-season cane. It is suggested that this difference is due to the fact that very little nitrogen was applied since the second-season cane had come into existence. After an extra application of nitrogen, the suckers caught up with the others in nitrogen in about four weeks' time.

have happened to these fields both to the first- and the second-season cane had we applied another and a later application of nitrogen. Could we not have saved mortality in big cane and stagnation in the young?

After these symptoms of nitrogen starvation had become quite pronounced and we had discovered that the second-season cane, which because of its age should be in greater vigor, had actually less nitrogen, we attempted to correct these conditions by applying an extra amount of 50 pounds of nitrogen per acre. The nitrogen analysis of the series following this application proves to be an interesting study. About three weeks after application we found that the second-season suckers were catching up with the first-season cane in per cent nitrogen, and in the fifth week the two groups were identical. The data also indicate that the relative uptake of nitrogen was greater in the case of the second-season cane—which was poorer to start with than the first-season cane.

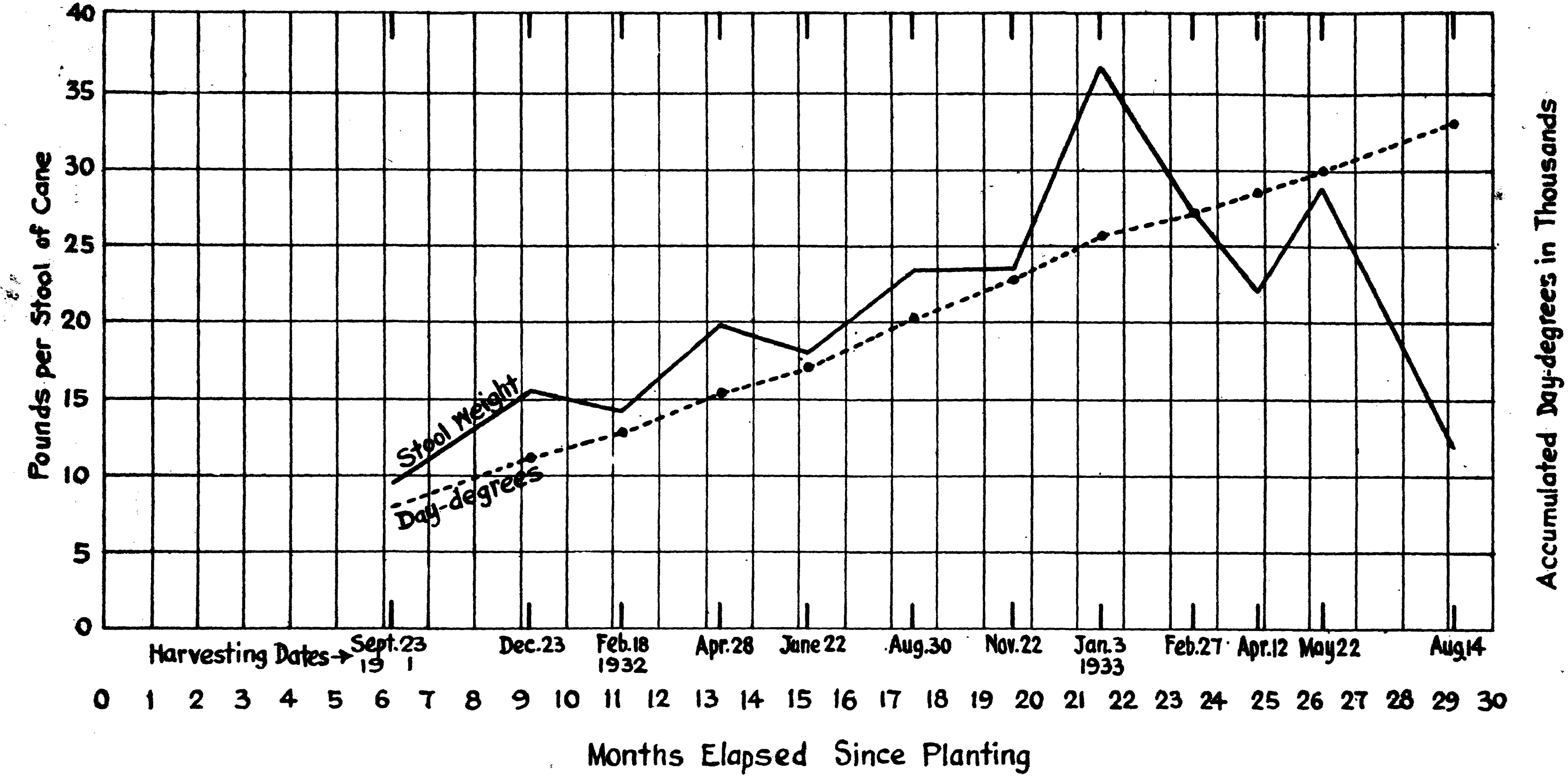
We would strongly suggest that this aspect of our fertilization policy receive more careful study. We are of the opinion that particularly under irrigated conditions it may be profitable to apply nitrogen later in the season. Should the quality go down somewhat, we may still make more sugar due to a bigger tonnage of cane.*

It may be regrettable to some that a study undertaken in response to an urge on the part of the industry to improve upon the quality of cane offers as one of its first practical suggestions the thought that we might with advantage have recourse first to higher tonnages under somewhat poorer juice quality. But such is the deduction to which the analysis of our data leads us.

XVII. Day-Degree and Cane Yield

We have made a study of the relation of day-degree to cane yield at various ages. Fig. 30 shows that there is a general agreement between the total day-degrees and yield of cane up to about 22 months, or up to the time the field as a whole has not started to deteriorate. It is also of interest to note that the average gain in weight of the first-order stalks of March-planted cane between September, 1931 and August, 1933, was practically the same as the gain in weight of September-planted cane between the same two dates. Naturally the total day-degrees were the same in both cases.

* To further elucidate our point let us take two types of stalks—one type having a large vigorously growing top and the other a very small, fan-shaped top indicating cessation or near cessation of growth. Let us further suppose that the vigorous type results from our more generous application of plant food and the short top from cutting down the nourishment. The big-top cane has a lower level of sucrose concentration and the short-top one a much higher level. If we were merely looking for quality we would certainly want the short-top type, but if we were more interested in total amount of sugar we might have chosen the big-top type. Here are some data in qualitative support of the above: We cut two stalks of the types as here suggested. The stalks were of about equal age and growing close together. The juice analysis showed the Brix of the dry-leaf part to be as follows: Big top 18.62°, small top 21.41°, and of the green-leaf part 14.53° and 15.23° respectively. But the weights of the green-leaf part in the two cases were 2.94 and 0.25 pounds respectively, and the dry-leaf parts 8.5 and 8.1 respectively. First of all, multiplying the weight of cane by the Brix we find the current production of total sugar (*i.e.* sugar in the green-leaf part) to be very much higher in the big top with a smaller Brix concentration than in the small top with a larger concentration. Secondly that the total sugar in the whole big stalk is greater than in the one with a small top.



Relation of average weight of a stool of cane at different dates to accumulated day-degrees.

Fig. 30. The agreement between day-degree and cane-yield was generally good until the field started to deteriorate after tasseling.

XVIII. Soil Temperature

Whenever the relation of temperature to cane growth is discussed someone is sure to enquire about the relation of soil temperature to some aspects of growth. At the start of this experiment we installed a thermograph to record temperature at one foot below the ground, with the purpose of utilizing the data in our study. A continuous record is available for the past years, but so far we have been unable to correlate the data with either the yield or the quality of cane.* There are, however, some points of interest about the data which we would like to bring out.

Study of some of the records reproduced (Figs. 31, 31-A) will show daily fluctuation in temperature when the cane was young and the soil exposed to the sun. As the cane started to close in, the weekly graph started to straighten out and from the first 5 or 6 months after planting to the last harvest at 30 months the graph remained almost a straight line from day to day. There were, however, variations from week to week and month to month. The difference between mean maximum air temperature and the soil temperature was only about 8° at the start of the experiment, this difference gradually increasing to 16° F. in the second year. Due to the effect of trash blanket and growing cane the soil temperature of the summer months of 1932 is much lower than the same months of 1931 while the air temperature is a little higher in 1932 than in 1931.

Another point of interest brought out by the thermograph data was that every Monday and Thursday at about eight in the morning the soil temperature went down a degree or two in the summer months and went up a degree or two in the winter months. Those were the days and the hours when we irrigated our cane. Evidently in the summer months the irrigation water was cooler than the soil and in the winter months the reverse. The graphs also show that it usually took about 48 hours for the soil temperature to come back to the normal weekly level.

Undoubtedly in areas using very cold mountain water the cooling effect will be even greater. If soil temperatures do govern growth processes to any marked extent, then this lowering of soil temperature may be of considerable practical interest in certain areas. Particularly is this true when we are putting on needless irrigations during the winter months.

XIX. Summary

This paper is a study of the composition of a cane crop and its influence on cane yield and juice quality. In this study it is shown that a cane crop, at any time, consists of stalks of different ages and consequently in different stages of vigor and maturity. The average yield and quality, being a composite of these different kinds of stalks, are naturally influenced by the relative proportion of these stalks at different ages.

Suckering: Suckering is found to be a continuous phenomenon in a field of cane. It is primarily influenced by self-shading due to plant competition. In-

* All through the literature, we find references to the dominant influence of soil temperature on the germination of seeds, on the microbiological activity and the CO_2 formation in the soil. We feel sure that the soil temperature must affect all the physical and chemical processes that are initiated in the root. Here at the Experiment Station we supply bottom heat to the young cane seedlings to obtain better growth, but we confess that we do not know of any experimental data which show the extent to which aerial growth of adult plants is affected by small variations in soil temperature.

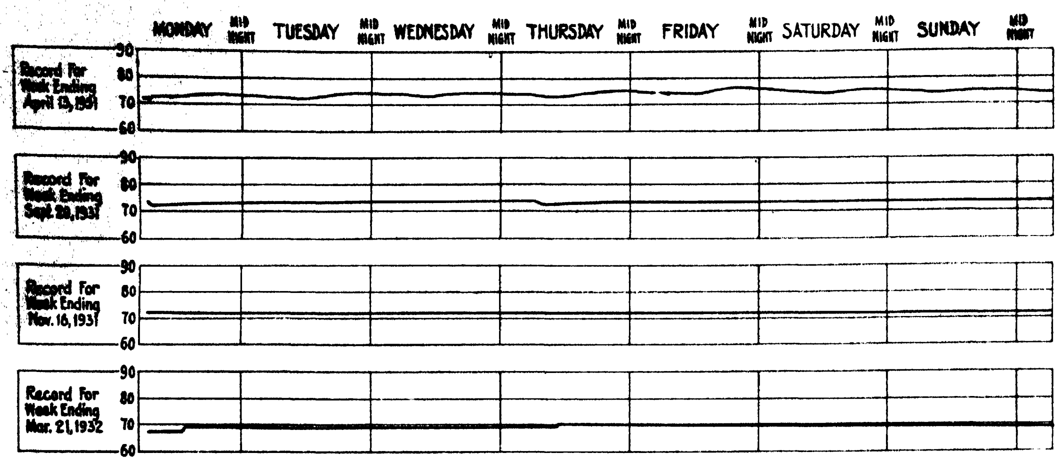


Fig. 31. Some typical weekly charts are here reproduced to show how the fluctuations in soil temperature are governed not only by the stand of cane but also by the temperature of the irrigation water in different seasons of the year.

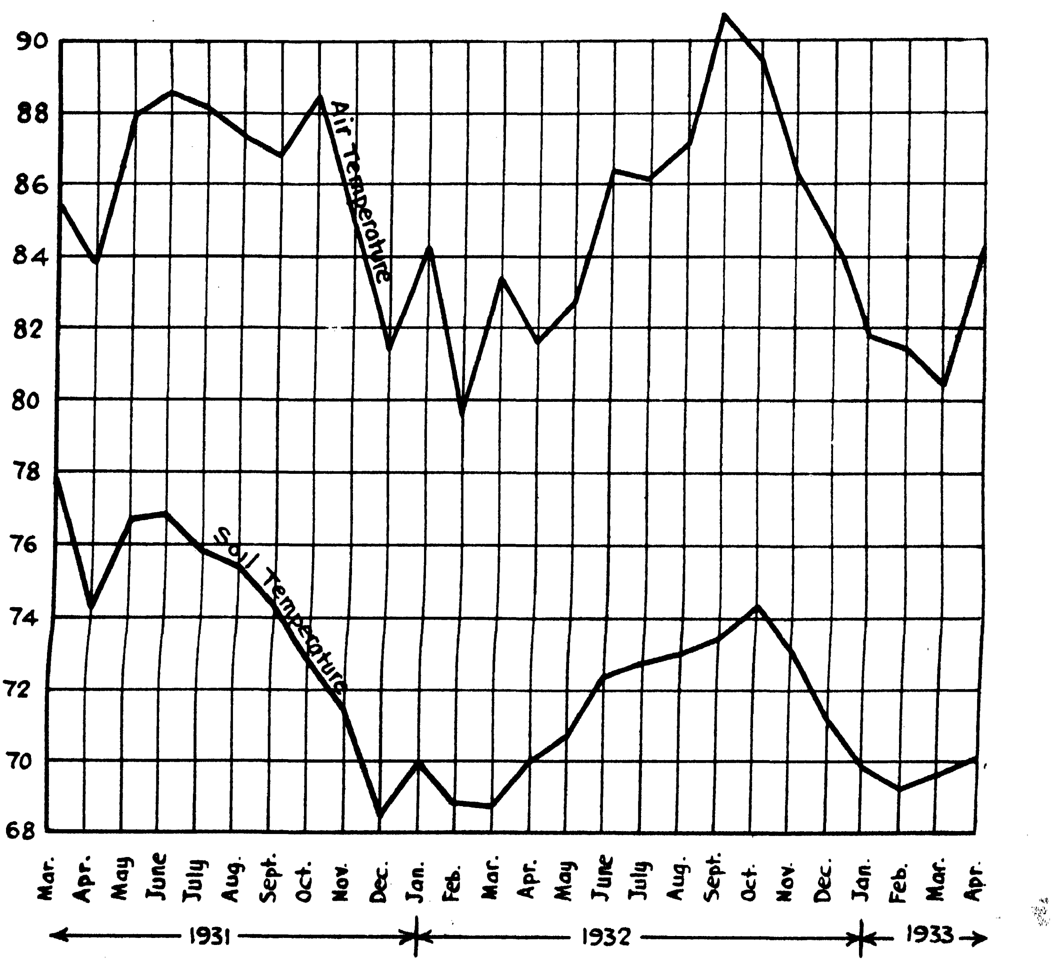


Fig. 31-A. When the cane is young the soil temperature at a depth of one foot is only about 8° below the mean maximum air temperature. The difference increases as the cane closes in. In the second year the difference increased from 8° to about 16°. Although the air temperatures of 1931 and 1932 are alike, the soil temperature of the summer of 1932 (under big cane) is much lower than that of the summer of 1931 (small cane). We do not know as yet if this difference is of significance to cane growth.

dependently of the season the number of suckers reaches a maximum between 4 and 5 months of age or just when the crop closes in. This maximum is followed by a decline to a more or less stable number of about 3 stalks per foot for H 109 cane.

Millable cane: A crop of H 109 under the experimental conditions consists very largely, 80 to 100 per cent, of stalks that germinate within 3 months after planting.

In our experiment, March-planted cane appears to be more suited to a long crop, and September-planted cane to a short crop. The extent of tasseling and its relation to the application of fertilizers appear to be considerations of utmost importance for determining the proper crop length.

Sucrose: Excellent juices have been obtained from both the first- and second-season cane in spite of a continuous application of 4 inches of irrigation a week to the very day of harvest. There was no indication of deterioration of juice with age in those stalks that remained sound; for the per cent of sucrose in all orders of stalks continued to improve to 29 months after planting, and both the second-season suckers and the lalas proved to be as good and at times better than the first-season cane in sucrose.

Sucrose in different parts of the same stalk: It has been very definitely brought out that the millable cane may be divided, from the viewpoint of quality, into two sections: (1) the dry-leaf cane, (2) the green-leaf cane (the green-leaf cane is defined as that part of the millable stalk where green leaves are still attached). At any stage in the development of the plant the dry-leaf section appears to be more or less mature. It is in the green-leaf section where active accumulation of sucrose is still going on. The dry-leaf section may then be considered as beyond the reach of ordinary cultural treatments.

The average juice of the whole stalk is a composite of the dry-leaf and the green-leaf sections and as such must be greatly influenced by the relative proportion, of juice by weight, of these two sections. The difference in the average quality of an old cane and a young cane may then be due primarily to the difference in the ratios of these two parts. It is suggested that maturity may more logically be considered as the shortening of the minimum of the green-leaf section, than as an arbitrary concentration of sucrose or glucose in the stalks.

Joint-to-joint analysis of stalks strengthens the points just brought out.

Second-season fertilization: The results suggest a re-examination of our second-season fertilization policy to see whether or not we have gone beyond the limits of best practice in avoiding fertilization of cane late in the crop.

Many other points of importance to a full understanding of the cane crop are also discussed; such as the extent of variations from stalk to stalk and within different parts of the same stalk, the effects of tasseling, shading, soil temperatures, etc.

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For the sake of simplicity all references to literature have been omitted in the text; however, a list of the more pertinent publications on this subject is given below. Discussions of more general interest will be found in the standard texts by Geerligs, Deerr, and Quintus.

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TABLE I

Relation of the number of shoots per stool at the age of ten weeks and the length of the primary stalk

Number of shoots per stool	Number of stools having the stated number of shoots	Average length of first-order stalks in the stools
6	3	14.7 inches
5	32	12.8 "
5	79	12.2 "
3	75	11.7 "
2	50	10.7 "
1	24	10.0 "
0	52	8.6 "

Total 315 stools or 9 lines of cane

TABLE II

Total Number of Shoots at Various Dates—Cane Planted March 17, 1931—Average of Sections A, B, C and F

Date	11/4/32	6/2/31	6/30/31	8/2/31	10/7/31	12/12/31	2/7/32	4/3/32	6/4/32	8/26/32
Average of outside lines	35	138	190	249	125	151	150	172	194	146
Average of first inside lines	35	122	173	197	98	100	91	96	123	106
Average of second inside lines	35	133	185	205	110	98	93	97	122	103
Approximate number of months since planting	1	2½	3½	4½	7	9	11	13½	15½	18

September Planting—Section H Only

Date	10/17/31	12/31/31	2/7/32	4/5/32	6/4/32	9/7/32
Outside lines*	35	179	233	207	131	96
First inside line	35	144	181	163	108	99
Second inside line	35	134	179	158	96	87
Approximate number of months since planting	1	3½	4½	7	9	12

* It has been explained in the body of the report that this was an outside line for a short time only. As the cane in the adjoining section got big this outside line ceased to be an outside line in the true sense.

TABLE III

No. of Shoots on	Oct. 17, 1931	Dec. 11, 1931	Increase or Decrease
Section A—Line 1 (outside)	124	145	+21
2 (inside)	102	98	— 4
3 (inside)	97	99	+ 2
Section B—Line 1 (outside)	114	155	+41
2 (inside)	91	106	+15
3 (inside)	114	106	— 8
Section C—Line 1 (outside)	127	166	+39
2 (inside)	99	99	0
3 (inside)	109	93	—16
Section F—Line 1	135	138	+ 3
2	98	96	— 2
3	118	93	—25

TABLE IV

Weight of millable cane and green top per line for different orders of stalks—March planting

Date of harvest	Approximate age in mos.	First-order. Pounds of		Second-order. Pounds of		Total weight in pounds of first, second and other orders	
		Millable cane	Green top	Millable cane	Green top	Millable cane	Green top
September 23, 1931	6¼	107.30	....	210.28	.....	317.58	.....
Dec. 23, 1931	9¼	188.25	....	377.75	.....	583.88	.....
February 17, 1932	11	184.95	....	317.69	.....	506.27	.....
April 28, 1932	13½	232.06	64.38	460.56	147.60	693.50	242.60
June 22, 1932	15¼	252.13	51.63	377.13	87.63	635.26	153.00
August 30, 1932	17½	261.38	42.70	539.38	97.50	820.01	154.20
November 2, 1932	19½	277.46	29.94	513.24	64.73	828.50	102.60
January 3, 1933	21½	358.09	25.74	775.03	62.53	1290.75	118.23
February 27, 1933	23½	247.16	17.89	600.49	29.47	943.66	66.38
April 12, 1933	24¾	232.79	16.27	429.90	31.02	770.47	70.53
May 22, 1933	26¼	125.44	10.32	704.83	45.85	1023.41	83.02
August 14, 1933	29	77.75	10.01	276.71	32.64	450.04	65.85

TABLE V

Number of stalks harvested per line at different ages
March-planted cane

Date of harvest	Approximate age of field in months	Number of first-order stalks: Total	Number of first-order stalks: Stalks with healthy tops only	Number of second-order stalks	Total number of stalks in the line
December 23, 1931......	9¼	35	35	88	123
February 17, 1932........	11	35	35	70	107
April 28, 1932............	13½	35	35	78	113
June 22, 1932............	15¼	35	29	60	96
August 30, 1932..........	17½	33	25	63	105
November 2, 1932........	19½	34	17	54	92
January 3, 1933..........	21½	33	26	66	120
February 27, 1933........	23½	26	10	53	91
April 12, 1933............	24¾	21	12	36	71
May 22, 1933..............	26¼	10	8	51	75
August 14, 1933..........	29	6	4	26	42

TABLE VI

Average weight of millable cane and green top of first-order stalks at different ages

Date of harvest	Approximate age in months	Millable cane in pounds: All stalks	Millable cane in pounds: Stalks with healthy tops only	Green weight in pounds
September 23, 1931.............	6¼	3.07	....	....
December 23, 1931.............	9¼	5.21	....	....
February 17, 1932.............	11	5.28	....	....
April 28, 1932.................	13½	6.63	....	1.84
June 22, 1932.................	15¼	7.31	8.20	1.50
August 30, 1932................	17½	8.03	9.24	1.31
November 2, 1932.............	19½	8.30	11.34	0.90
January 3, 1933...............	21½	10.86	12.14	0.78
February 27, 1933.............	23½	9.50	13.32	0.69
April 12, 1933.................	24¾	11.09	15.23	0.78
May 22, 1933.................	26¼	12.54	13.55	1.03
August 14, 1933..............	29	12.96	16.94	1.67

TABLE VII

Total weight in pounds of millable cane and green top of different orders harvested at different ages—September-planted cane

Harvesting date	Approximate age in months	First-order: Millable cane	First-order: Green top	Second-order: Millable cane	Second-order: Green top	All orders—First, second and others: Millable cane	All orders—First, second and others: Green top
July 1, 1932..........	9½	160.0	64.75	175.50	84.75	372.0	176.12
September 8, 1932.....	11¾	220.0	55.15	519.0	141.10	754.81	200.69
November 14, 1932....	14	289.95	61.05	476.10	111.48	777.55	176.16
February 6, 1933......	16½	275.97	51.98	487.14	86.77	744.11	138.75
March 29, 1933........	18½	255.99	39.42	472.93	86.23	728.92	129.90
May 15, 1933..........	20	266.53	37.42	466.56	68.66	735.22	113.33
August 15, 1933.......	23	313.48	32.35	478.66	51.51	868.24	178.73
October 17, 1933......	25	309.98	31.49	457.35	47.39	840.86	110.39

TABLE VIII

Number of stalks harvested per line at different ages—September-planted cane

Harvesting date	Approximate age in months	First-order stalks	Second-order stalks	All orders of stalks
July 1, 1932	9½	35	55	115
September 8, 1932	11¾	35	83	121
November 14, 1932	14	35	65	103
February 6, 1933	16½	34	59	93
March 29, 1933	18½	29	55	85
May 15, 1933	20	33	59	93
August 15, 1933	23	31	52	90
October 17, 1933	25	30	44	79

TABLE IX

Average weight of millable cane and green top* of first- and second-order stalks September-planted cane

Harvesting date	Approximate age in months	First-order Millable cane	First-order Green top	Second-order Millable cane	Second-order Green top
July 1, 1932	9½	4.83	1.85	3.19	1.54
September 8, 1932	11¾	6.29	1.60	6.25	1.70
November 14, 1932	14	8.28	1.74	7.32	1.72
February 6, 1933	16½	8.12	1.53	8.26	1.47
March 29, 1933	18½	8.83	1.36	8.60	1.57
May 15, 1933	20	8.08	1.13	7.91	1.16
August 15, 1933	23	10.11	1.43	9.21	1.68
October 17, 1933	25	10.33	1.05	10.39	1.08

* Includes the green weight of lalas growing on first- and second-order stalks.

TABLE X

Average weight of millable cane per running foot of row in the shaded and exposed sections of the same line of cane

Date of harvest	Age of the crop in months	Pounds millable cane per foot Shaded section	Pounds millable cane per foot Exposed section
July 1, 1932	10	9.00	10.56
September 8, 1932	11¾	11.62	13.21
November 14, 1932	14	11.83	20.68
February 4, 1933	16½	20.39	19.26
March 29, 1933	18½	14.20	19.10
May 15, 1933	20	11.71	21.64
July 10, 1933	22	18.95	21.17

TABLE XI

Harvesting date	Age of field in months	First-order		Second-order		Third-order		Fifth-order		Sixth-order		Seventh-order		Eighth-order		Higher order	
		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Sept. 23, 1931....	6¼	7.63	...	5.62	...	...	...	...	...	...	...	...	...	...	...	...	...
Dec. 23, 1931.....	9¼	9.75	2.04	8.14	2.32	6.30	2.54	...	...	...	...	...	...	...	...	...	...
Feb. 18, 1932.....	10¾	12.65	1.33	12.83	1.21	9.72	1.38	...	...	...	...	...	...	...	...	...	...
Apr. 28, 1932......	13½	13.72	.97	14.13	.78	...	...	...	...	...	...	...	...	...	...	...	...
June 22, 1932.....	15¼	15.09	1.02	15.69	.86	...	...	...	...	...	...	...	...	...	...	...	...
Aug. 30, 1932.....	17½	15.29	1.01	15.37	.64	...	...	...	...	...	...	8.92	1.72	...	...	...	...
Nov. 2, 1932......	19½	14.42	.91	15.05	.89	16.55	.59	14.89	.89	13.78	1.17	12.26	1.40	...	...	...	...
Jan. 4, 1933.......	21½	15.25	.90	15.55	.67	...	...	...	...	16.29	.50	15.01	0.81	...	...	...	...
Feb. 28, 1933......	23¼	13.67	1.03	14.02	.87	13.95	.93	14.89	.63	16.89	.25	16.31	0.37	13.74	0.56	...	...
Mar. 16, 1933......	24	16.51	.57	16.10	.56	...	...	...	...	16.14	.39	13.55	0.56	...	...	...	...
Apr. 13, 1933......	25	16.69	.50	16.48	.53	17.61	.27	...	...	19.09	.09	17.99	0.23	...	...	...	...
May 23, 1933......	26¼	17.93	.42	16.61	.49	16.40	.60	17.43	.59	18.80	.22	17.85	0.27	...	...	...	...
Aug. 15, 1933.....	28	18.04	.40	17.54	.56	18.98	.21	20.93	.33	17.67	.33	15.28	0.71	14.36	0.81	13.08	1.07

TABLE XII

Percentage of sucrose and glucose in different sections of the stalks

(A) Harvested Sept. 8, 1932—Outside line—Age about 18 months

	First-order		Second-order		Fifth-order		Sixth-order		Seventh-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4′	18.51	0.66	18.97	0.33	....	...	....	...	...	....
Middle	18.34	0.34	18.77	0.20	15.52	0.50	....	...	...	....
Top 4′	17.52	0.44	17.23	0.80	15.19	0.87	14.30	0.99	0.86	14.22
Millable green-leaf	12.85	1.88	12.52	1.96	12.18	1.54	9.98	1.70	1.58	9.58

Lalas (composite of whole stalk)
Sucrose=16.38%
Glucose= 0.80%

(B) Harvested Dec. 20, 1932—Inside line—Age about 21 months

	First-order		Tasseled		Untasseled		Sixth-order		Seventh-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4′	15.33	0.46	15.78	0.56	13.41	0.87	15.39	0.35	....	...
Middle	16.45	0.44	16.34	0.50	14.23	0.78	14.91	0.66	13.35	1.18
Top 4′	15.62	1.03	15.15	1.14	14.92	1.14	15.10	0.80	13.64	1.11
Millable green-leaf	12.35	1.67	12.36	1.65	12.75	1.70	12.30	1.57	9.42	1.77

(C) Harvested April 11, 1933—Inside line—Age about 25 months

	First-order		Second-order		Third-order		Fifth-order		Sixth-order		Seventh-order		Eighth-order	
	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
Bottom 4′	15.69	0.45	15.62	0.42	16.67	0.24	17.89	0.13	18.35	0.17	....	...	....	...
Middle	17.71	0.38	16.56	0.52	15.76	0.54	18.93	...	18.28	0.37	17.06	0.36	....	...
Top 4′	18.94	0.21	17.18	0.45	17.73	0.30	19.13	...	18.67	0.14	18.05	0.19	14.44	0.63
Millable green-leaf	13.61	...	13.61	0.77	....	...	....	...	....	...	....	...	....	...

Lala on first- and second-orders (whole stalks)
Sucrose=14.72%

TABLE XIII

Percentage of sucrose and glucose in September-planted cane at different ages

Harvesting date	Field age in months	First-order Sucrose	Glucose	Q. R.	Second-order Sucrose	Glucose	Q. R.	Third-order Sucrose	Glucose	Q. R.
July 1, 1932	9½	11.38	2.12	13.45	9.43	2.59	17.90	5.97	3.06	34.99
September 9, 1932	11¾	15.74	2.46	8.68	15.07	1.34	9.31	12.94	1.62	11.51
November 15, 1932	14	14.97	0.99	9.04	14.91	1.02	9.22	14.32	0.81	9.63
February 4, 1933	16½	17.05	0.47	7.68	16.58	0.58	7.92	....	...	....
March 30, 1933	18½	17.86	0.38	7.35	17.72	0.39	7.44	....	...	....
May 16, 1933	20	17.43	0.47	7.52	17.56	0.47	7.47	....	...	....
August 15, 1933	23	18.45	0.33	7.04	17.98	0.37	7.21	....	...	....
October 17, 1933	25	18.50	0.26	7.00	18.58	0.25	6.99	....	...	....

TABLE XIV

Comparison of the weights and juice quality of different sections of tasseled and untasseled stalks from the same stools

	Weights in Pounds				Per cent Sucrose in Juice			
	Bottom 3′	Middle	Top 3′	Millable green-leaf	Bottom 3′	Middle	Top 3′	Millable green-leaf
Tasseled	2.88	8.19	2.79	1.22	16.32	16.38	15.79	12.62
Not tasseled	2.66	6.07	2.31	1.00	14.97	16.00	16.27	13.29

TABLE XV

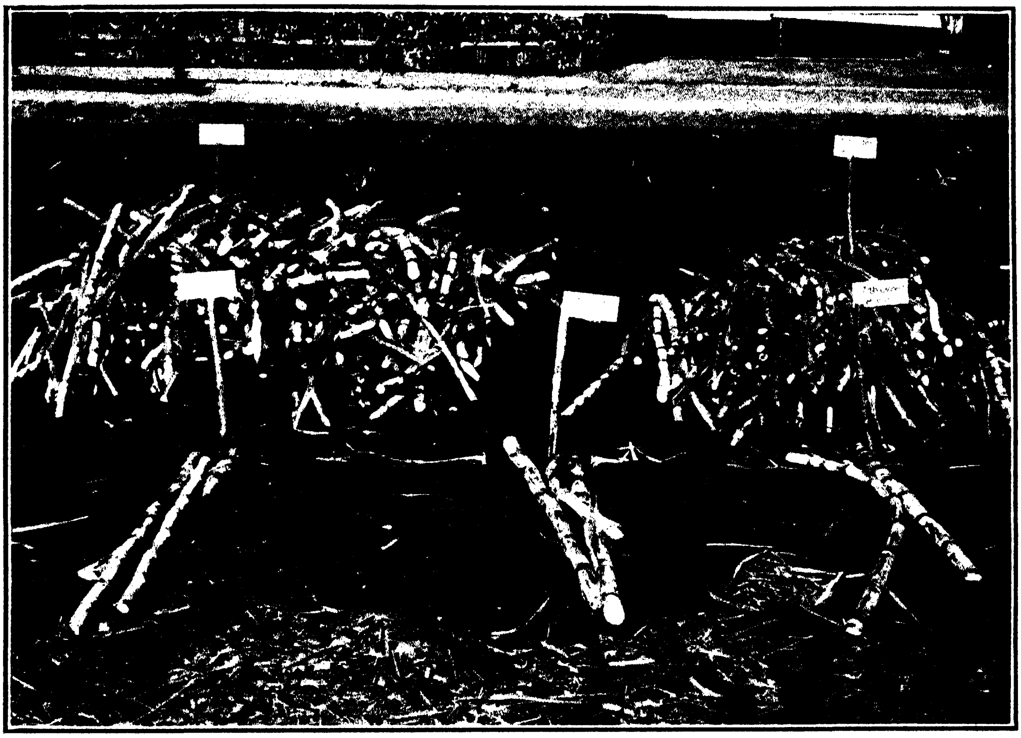
Percentage of total nitrogen in the first- and second-season cane*

	First-season cane			Second-season cane		
	Green top	Millable green-leaf	Dry-leaf	Green top	Millable green-leaf	Dry-leaf
Before N was applied............	0.749	0.146	0.106	0.673	0.122	0.122
2 days after N was applied.......	0.730	0.150	0.108	0.594	0.116	0.095
4 " " N " "	0.816	0.201	0.116	0.676	0.108	0.093
7 " " N " "	0.735	0.162	0.127	0.598	0.118	0.106
2 weeks " N " "	0.757	0.122	0.085	0.685	0.166	0.135
3 " " N " "	0.784	0.162	0.099	0.749	0.127	0.100
4 " " N " "	0.933	0.192	0.094	0.930	0.217	0.113
5 " " N " "	0.949	0.224	0.113	1.012	0.170	0.127
11 " " N " "	0.890	0.220	0.130	0.854	0.240	0.118

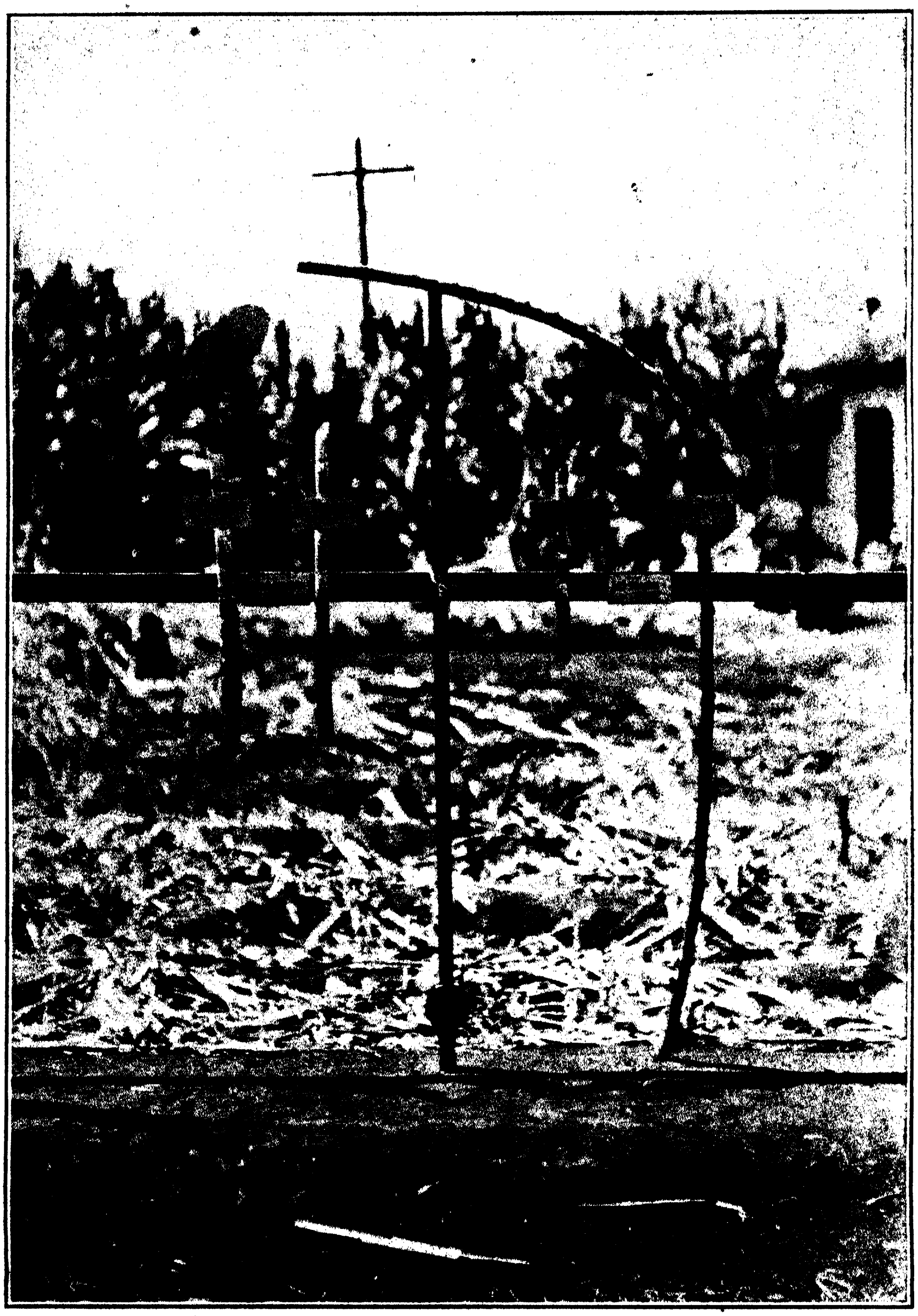
* First-season cane is normally the stalks that come up within the year of planting. In this paper first-season cane includes cane up to fourth order. Fifth and higher orders are second-season cane.

Showing the March-planted cane (big cane) to the right and the September-planted cane (small cane) to the left. The right end stools of small cane were shaded in the forenoon by the big cane. These stools were late in stooling out and at harvest the stalks weighed less and had less sucrose than the stools towards the left which received full sunlight.

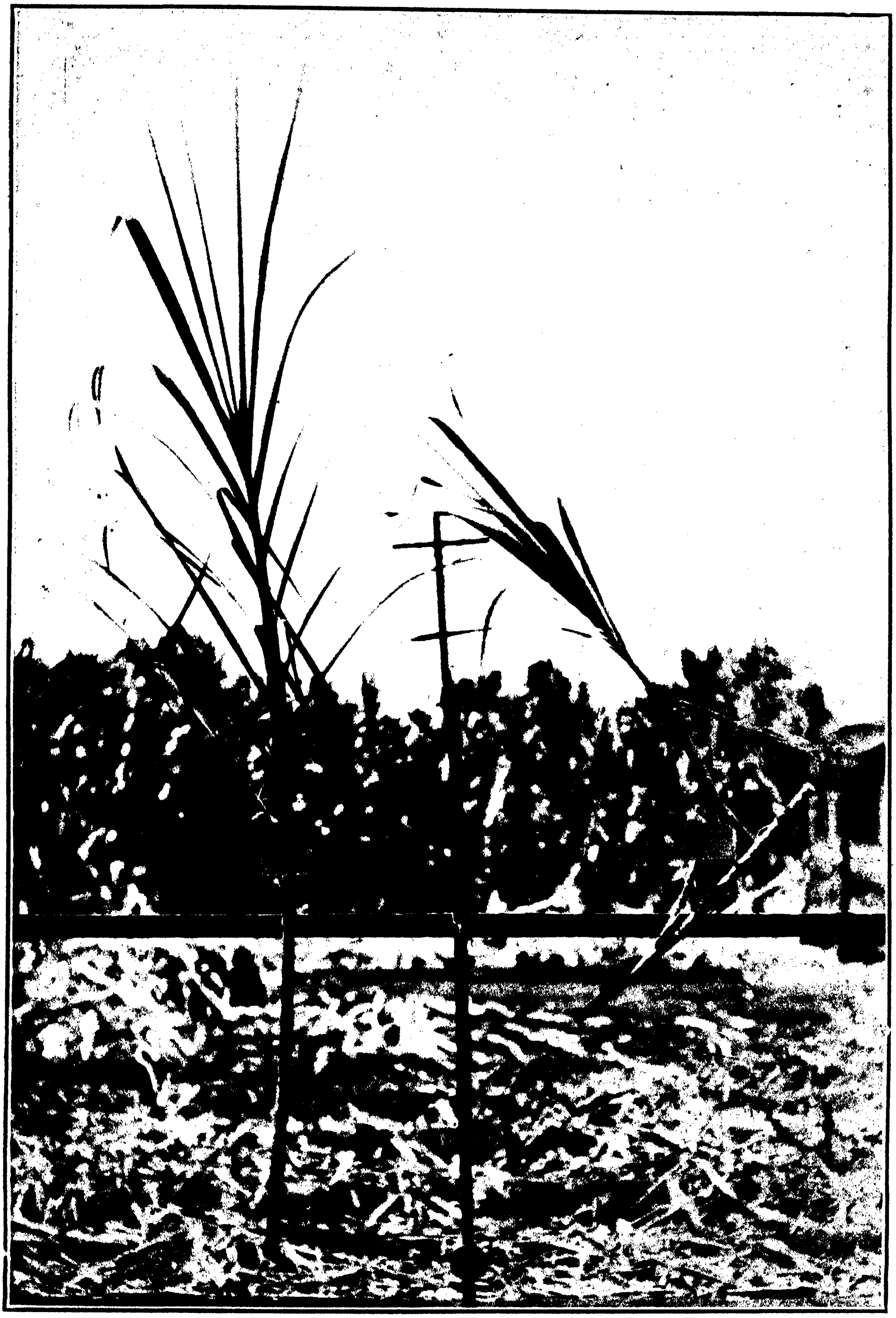
All the stalks shown in the picture grew originally from one single eye of cane. This one stool is from an outside row of cane and it contains stalks ranging in age from 4 months to 18 months. This is an extreme case to be sure, but this illustrates that under favorable conditions of light, space, and food, suckering is a continuous process in a field of cane.



Showing the quantity of cane of different orders harvested from one inside line of cane in this experiment. At the time of harvest the field was 20 months old.



This illustrates that in a first-season cane, the green-leaf part (the part containing little sucrose and much impurity) constitutes only a seventh or an eighth of the whole stalk. In the second-season sucker, this green part is fully half as much as the whole stalk. The relative proportion of this green part of the stalk to the rest of the stalk has a very important bearing on the average richness of the whole stalk.



The stick to the left is a sucker of the fifth order. At the time of harvest it was 10 months old. To the right is a lala growing from a first-season cane, only part of which is shown. This lala is also 10 months old, but the richness of juice of the lala is very much higher than the fifth-order shoot with which it is comparable in age and nearly approaches the richness of the first-season cane on which this lala is growing.

Here are three stalks in different stages of vigor as shown clearly by the manner of growth of the tops—by the spread and number of leaves, etc. The most vigorous one on the extreme left has a large green-leaf section, the one on the extreme right a very small green-leaf section of millable cane. It is suggested that the maturity of a stalk can well be judged by noting the length of this green-leaf part and the proportion it bears to the whole stalk.

The above illustration shows a first-season cane from September planting carrying four millable lalas; such stalks are not common in a cane field. All these lalas had as good juice as the mother stalk and are referred to in the text under the heading "Lalas."

Boron Deficiency Symptoms In Sugar Cane

By J. P. Martin

Introduction

In recent years, plant physiologists have demonstrated that small amounts of chemical elements such as manganese, boron, zinc and copper are essential for normal plant growth. Previous to this, only ten elements were considered necessary for plant growth, namely, carbon, oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and iron.

It has been shown by Lee and McHargue (5), Davis (2), and Martin (6), that manganese is essential for the growth of sugar cane in soil, sand or water cultures. Moir (11) stated that small amounts of manganese are necessary for cane growth under field conditions at Olaa Sugar Company, Ltd., Hawaii. Allison (1), in Florida, reported an excellent growth response with sugar cane when manganese and copper were applied to specific types of soil. The soil, which received copper at the rate of 75 pounds per acre of copper sulphate, produced a normal stand of cane, whereas a total growth failure resulted in the untreated areas. McHargue (9) has demonstrated the importance of small quantities of manganese in relation to the growth of Kentucky blue grass.

Johnston (3) has shown that the potato plant required one-half of a part per million of boron for normal growth, and that 5 p. p. m. were extremely toxic to the plant. Sommer (12) found that small quantities of boron were essential for the growth of peas, sunflowers, lettuce, barley, sugar beets and many other plants. Warington (14, 15) proved that boron was essential for the growth of the broad bean. Johnston and Dore (4) established the fact that boron is essential for the growth of the tomato plant. Sommer and Lipman (13) have presented evidence "on the indispensable nature of zinc and boron for higher green plants." McHargue and Calfee (10) demonstrated that lettuce plants grown in nutrient solutions containing quantities of boron from 0.4 to 0.9 p. p. m. produced a vigorous growth with no evidence of boron deficiency. However, with the 0.9 p. p. m., a slight toxic effect was noticed, while concentrations above this amount proved to be decidedly toxic.

In Java, van den Honert (16) found that a trace of boron was essential for normal growth of the sugar cane plant. His investigations, which had to do with the nutrition of the variety P. O. J. 2878, were carried out in sand cultures. He stated that 0.1 mg. of boron per liter of soil solution was sufficient for normal growth. A number of other references might be cited where elements in small amounts only have been found necessary for plant growth.

Martin (8) has shown that a depressed or retarded cane growth results when any one of eight of the essential elements is omitted in sand or water cultures. In each case specific leaf and stalk symptoms of malnutrition were manifested by the cane plant. Under field conditions the growth of the cane plant depends largely on the presence and availability of the essential elements in the soil. A

deficiency of one of these elements in the soil may be the limiting factor for cane growth, and specific leaf and stalk symptoms of malnutrition appear on the plants in the field as a result of such a deficiency. The deficiency symptoms that develop on the cane plants in the field are proving to be similar to those that occur on plants grown in sand or water cultures. Thus the diagnosis of the cause of certain growth failures (malnutrition type) occurring in various sugar cane fields has been expedited by a knowledge of these nutritional deficiency symptoms artificially produced on plants grown in culture solutions.

The object of this paper is to describe the symptoms of boron deficiency as produced on sugar cane grown in water cultures, in order that these symptoms may readily be recognized should they appear on sugar cane growing under field conditions. The studies reported herein were started during the early part of 1933 and were completed in January, 1934.

Experimental Procedure

The nutrient solution employed in these studies was one that, in previous nutritional investigations by the writer, proved to be extremely favorable for the growth of sugar cane. The chemical composition of this solution is given in Table I, while the p. p. m. of each element are presented in Table II.

Chemically pure salts, "Baker's Analyzed," and distilled water were used throughout these experiments; no attempt was made to purify the chemicals used. The fact that boron-deficiency symptoms developed on the cane plants in the boron-free solutions showed the chemicals to be exceptionally free from boron.

The hydrogen-ion concentration of the nutrient solution had a pH value of 5.2. In earlier studies, Martin (7) showed that the optimum pH value for the growth of sugar cane in water cultures is 4.8 to 5.2.

TABLE I

Partial Volume Molecular Concentrations per Liter of Compounds in the Nutrient Solution

Compound	V. M. C.
KH_2PO_4	.001
KNO_3	.003
$Ca(NO_3)_2.4H_2O$	.003
$CaCl_2.6H_2O$	.004
$MgSO_4.7H_2O$	.001
H_3BO_3	.00002
$Na_2SiO_3.9H_2O$	.00001

Iron and manganese were added at the rate of 10 and .25 p. p. m. per liter from $FeSO_4.(NH_4)_2 SO_4.6H_2O$, and $MnSO_4$, respectively.

TABLE II

Parts per Million of Each Element in the Nutrient Solution

Element	P. P. M.
Nitrogen	126
Phosphorus	31
Potassium	156
Calcium	280
Magnesium	24
Sulphur	32
Chlorine	284
Iron	10
Sodium	.23
Silica	.28
Boron	.22
Manganese	.25

Cuttings of the following sugar cane varieties, H 109, P. O. J. 36, P. O. J. 2878, Yellow Caledonia and Badila, were germinated in black volcanic sand. Tap water was applied to the sand during the germination of the cane cuttings. Shoots of uniform size approximately 12 to 14 inches in height were removed from the cuttings and transferred to the complete nutrient solution which contained boron. The majority of the young shoots had developed shoot roots and a well-established root system quickly developed on the plants in the nutrient solution. These plants were grown in the complete nutrient solution for five weeks in order that plants of a uniform size might be selected for the experiment. During this period the cane plants made what was considered a normal growth.

The containers used in these studies were one-gallon earthenware jars having a glazed inner surface. A two-piece lid of redwood with a 1.5-inch hole in its center was made so that it covered the top of the container. The cane plant was placed through the hole of the cover and held firmly in an upright position by placing two halves of a large cork around the plant and then by placing the cork and the plant as a unit tightly into the circular hole in the cover. With this arrangement the position of the plant could easily be adjusted and the root system readily examined at all times.

Plants of a uniform size which had been growing for five weeks in the complete nutrient solution were selected. One-half the number of plants of each variety received the complete nutrient solution, while the other half received the minus-boron solution. At first, the nutrient solutions were changed once a week but later, as the plants developed, it was necessary to renew the solutions once every four or five days.

For the purpose of studying the growth of the cane plants when boron was omitted, only two nutrient solutions were necessary. In other words, the growth of the plants in the complete nutrient solution was compared with the growth of plants of similar age in a boron-free solution, the only difference being the presence of .22 p. p. m. of boron in the former solution as against the absence of this amount of boron in the latter solution.

External Symptoms

The most marked effect upon the cane plants when grown in the boron-free nutrient solution was the retardation of growth, the development of distorted leaves, the chlorotic condition of the young leaves and the presence of definite lesions on the leaves and within the stalks. The plants quickly died if boron was not returned to the culture solution. The depressed growth, the distorted leaves, the chlorotic leaf condition and, to some extent, the leaf symptoms are shown in Figs. 1 and 2. The leaf symptoms are shown in greater detail in Figs. 3 and 4.

The young leaves of P. O. J. 36 (Fig. 1) which developed in the minus-boron solution became very much shortened in length and narrowed in width at the base. The young leaves also became chlorotic. The edges and tips of the affected leaves developed irregularly which made it appear as though portions of the leaves had fallen away; the edges of the tissue so affected were dark reddish brown to black in color. The irregular edges had a burned appearance. When boron was again added to the nutrient solution this particular plant resumed a normal growth.

The H 109 plant on the right in Fig. 2 also shows the distorted and chlorotic condition of the young leaves. The growth of this plant was very much depressed when compared with the growth of plants of similar age which received boron (Fig. 2, left).

The first leaf symptoms to develop, as a result of boron deficiency, appeared on the young leaves as minute, elongated, watery spots. The initial spots or lesions developed parallel to the vascular bundles of the leaves and produced a definite leaf striping (Fig. 3, A, B). In one experiment leaf symptoms were observed at the end of 30 days but, as a rule, the first symptoms developed from one to two months after boron was omitted from the nutrient solution.

The initial lesions soon began to enlarge and were characterized on the upper and lower leaf surfaces by small, longitudinal, sunken areas or depressions in the center of the lesion while, on the lower leaf surfaces, minute, elongated, gall-like bodies frequently developed. The upper and lower leaf symptoms are shown in Figs. 3 and 4.

Three to four weeks after the first symptoms appeared many of the lesions were 3 to 10 mm. in length and 1 to 3 mm. in width; in some instances individual lesions measured 20 to 50 mm. in length and 2 to 5 mm. in width.

The more mature lesions manifested a dark red center surrounded by chlorotic tissue. In the mature lesions the leaf tissues separated, forming a definite crack or fracture in the leaf. The inner edges of the leaf fracture were serrate, giving the appearance of ladder-like or chain-like lesions (Fig. 4).

In a few instances stalks manifested internal narrow, brownish streaks at and slightly below the growing point. These lesions varied from 1 to 20 mm. in length and from 1 to 2 mm. in width. Occasionally these longitudinal lesions in the stalk showed the ladder-like arrangement somewhat similar to those in the leaf. No external stalk symptoms were observed on the plants which were grown in the boron-free nutrient solution.

Fig. 1. Showing the development of P. O. J. 36 in a boron-free nutrient solution. The young leaves are chlorotic and badly distorted. This plant made a normal growth when boron was again added to the nutrient solution.

Fig. 2. H 109 cane plants. The plant on the left received boron, while the plant on the right was deprived of boron. Note the depressed growth and the distorted leaf development of the latter.

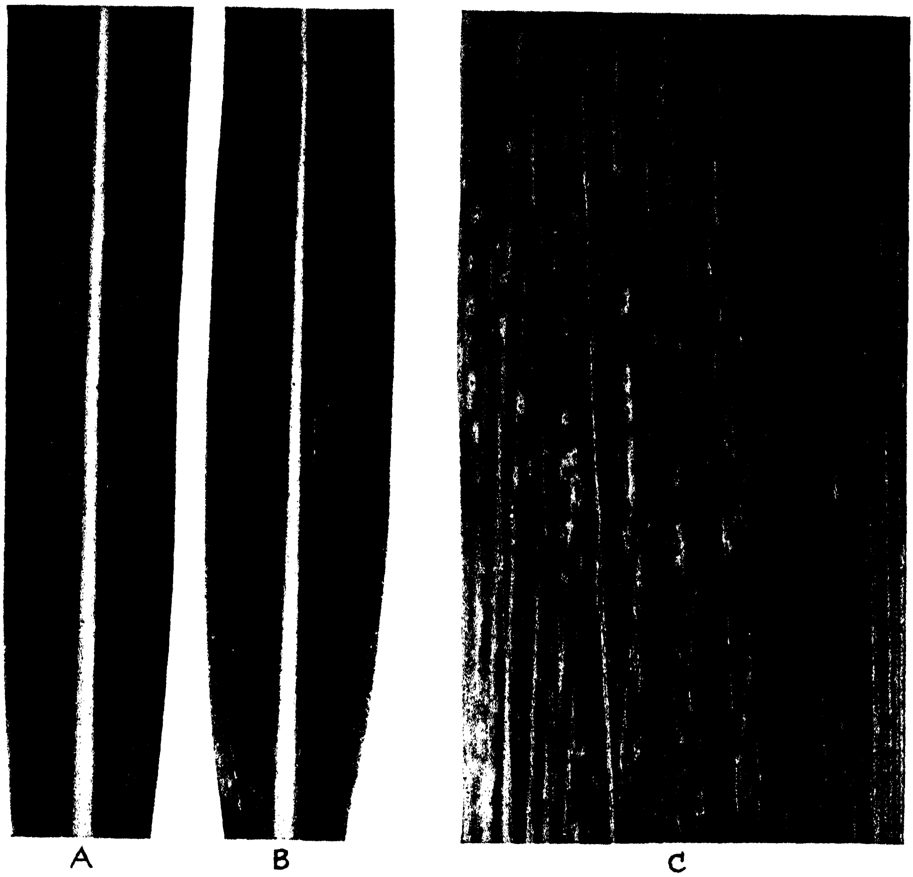


Fig. 3. Leaf symptoms of boron deficiency on H 109 cane. Leaves A and B show a definite striping which develops parallel to the vascular bundles and a narrowing of the leaves at the base. On the lower surface of these leaves, small longitudinal gall-like bodies develop as shown in C. (A, B×0.5; C×3.2.)

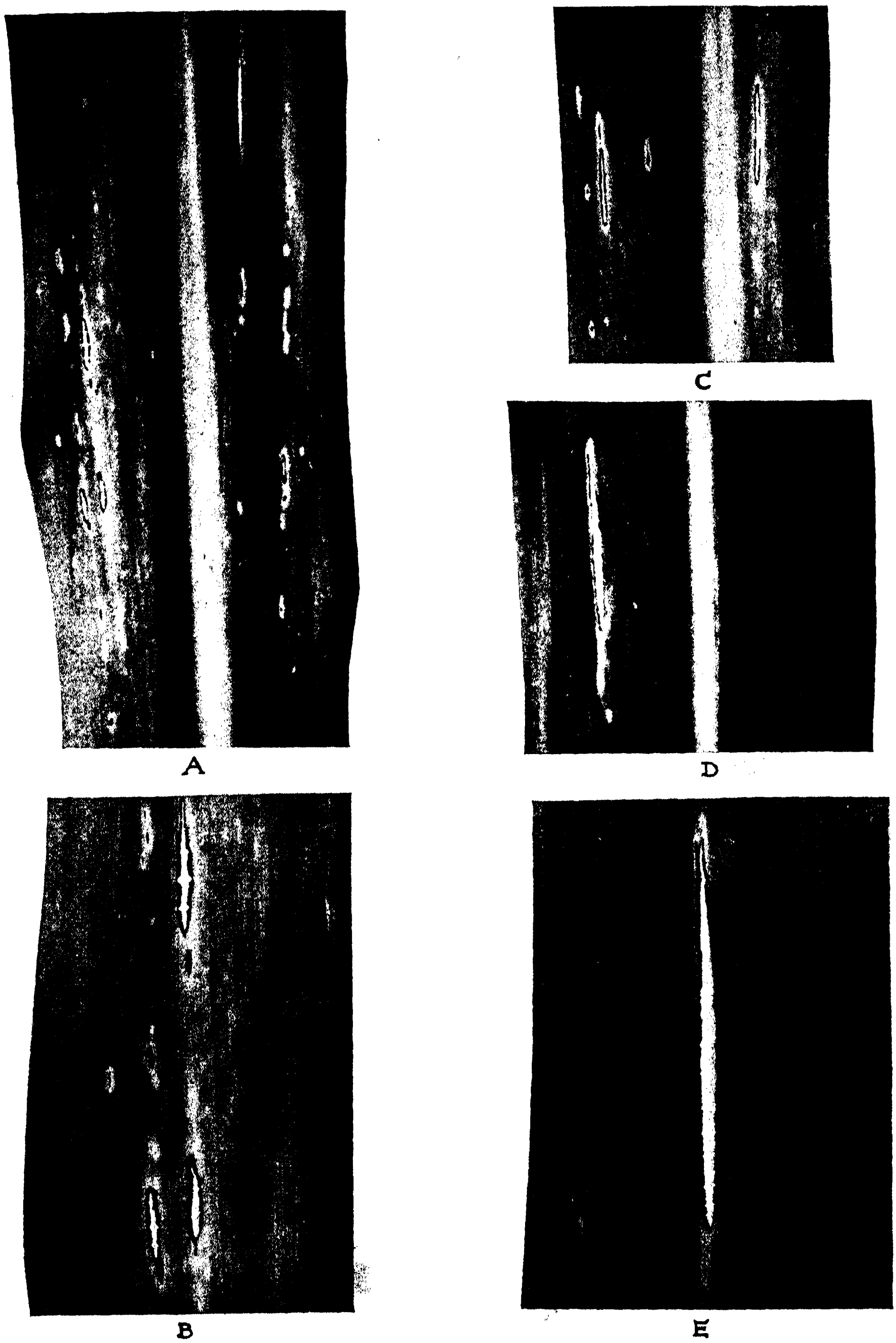


Fig. 4. Leaf symptoms of boron deficiency on Badila cane. A(×1.5), the development of the youngest to the oldest lesions on upper leaf surface. B (×3), an enlarged section of left center of A. C (×1.3), leaf symptoms on lower leaf surface. D (×1.9), a longitudinal lesion and a few of the earliest symptoms on the upper leaf surface. E (×3), an enlargement of D, note the serrate edges of the open leaf crack.

Microscopic Symptoms

A histological study of the lesions that appeared on the leaves showed a derangement of cells within certain tissues. Transverse sections of these lesions in various stages of development were made from fresh as well as from fixed and embedded material.

The transverse sections shown in Fig. 5 were taken from leaves of Badila cane on which boron-deficiency symptoms developed. Although normal in many respects, it is seen (Fig. 5, A) that the lignified fiber cells (hypodermal sclerenchyma) at the upper and lower sides of the large chlorophyll-bearing bundle sheath appear to be loosely organized, small in size, irregular in shape, and poorly developed. Many vascular bundles were examined and this condition seemed to be quite general, as again shown in Fig. 6, A, B. One characteristic of these fiber cells when normal is their high lignin and silica content which explains their degree of hardness and tensile strength. This abnormal condition, associated with boron deficiency, suggests an existing relationship between silica metabolism and boron deficiency.

A cross section through one of the earlier stages of a leaf lesion shows (Fig. 5, B, C,) that certain of the lower cells in the chlorophyll-bearing bundle sheath have become greatly enlarged and drawn toward the lower leaf surface. Normally, these particular cells have the form of short cylinders with the long axis of the cell parallel to the vascular bundles (the veins of the leaf). This abnormal cell development may occur between the large rhomboid and small round bundles or between the latter and the medium large oval bundles. Later, this stimulated cell growth pushes through the lower leaf surface (Fig. 5, D, E) and appears as elongated gall-like bodies on the lower leaf surface (Fig. 3, C) between the large vascular bundles.

Transverse sections, through young leaf lesions having elongated reddish to dark brown centers, showed that necrotic tissue extends through the leaf, which, at this point, becomes deeply constricted (Fig. 5, F, G). Here again the lesion develops between two vascular bundles and extends from the lower to the upper leaf surface. These constrictions apparently account for the depressions that occur in the center of the lesions, as shown in Fig. 4, A, B. The leaf tissues in the lesion at this stage are greatly weakened and eventually split, thus forming open cracks in the leaves, also shown in Fig. 4.

Transverse sections through a leaf lesion where the leaf split has not as yet developed is shown in Fig. 5, H, I. In each case the constriction is much deeper on the lower than on the upper surface of the leaf; the epidermis is distorted and broken and the development of the tissue is abnormal.

No abnormal development of the phloem or xylem was observed other than a possible crowding effect which resulted from the greatly enlarged bundle sheath cells. However, these tissues become involved in the advanced development of the lesions before the leaf fractures develop.

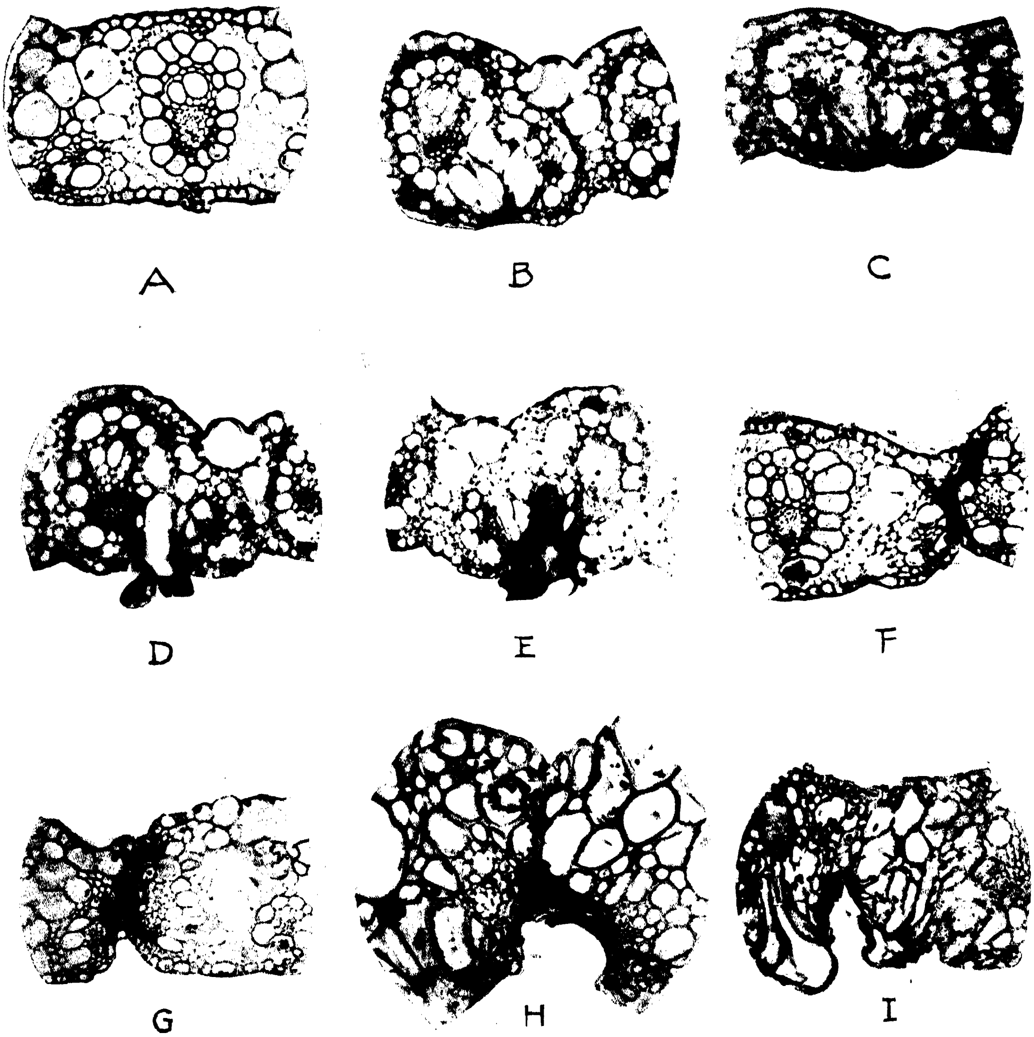
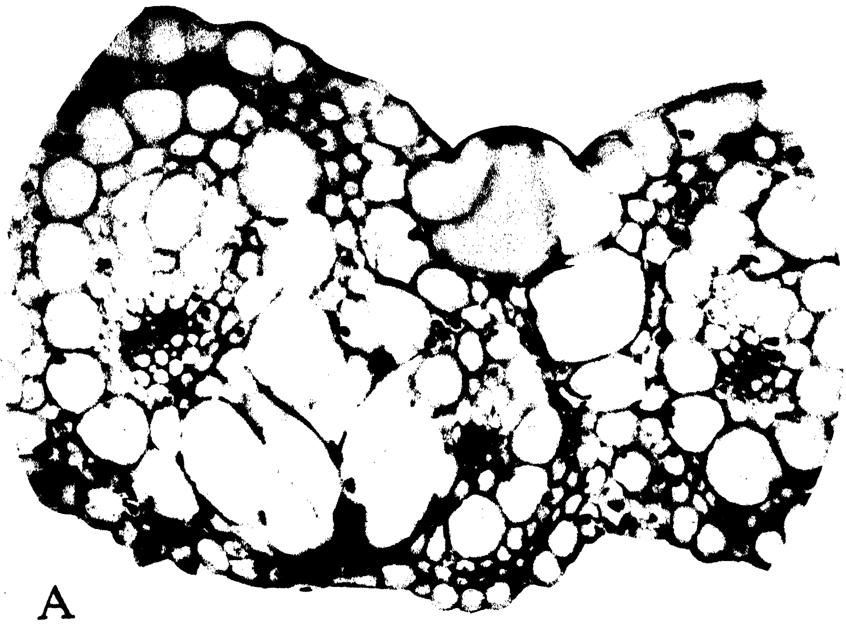
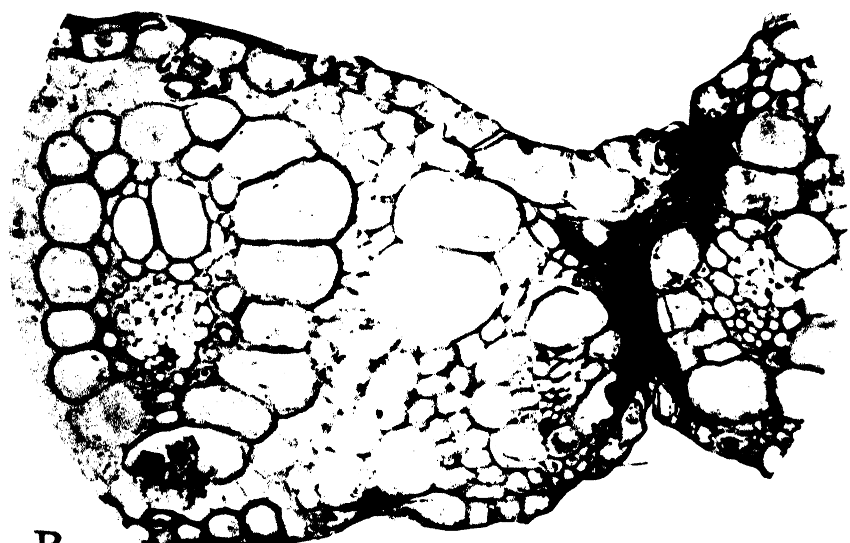


Fig. 5. Transverse sections of leaves of Badila cane grown in a boron-free nutrient solution. A, normal structure. B and C, the greatly enlarged cells in the chlorophyll-bearing bundle sheath which develop between two vascular bundles and the tendency of these "giant cells" to focus at a point near the lower leaf surface. D and E, the stimulated cells which have pushed through the lower epidermal surface to form the elongated gall-like body on the lower leaf surface. F and G, the deep constrictions and necrotic tissues extending through the leaf; at these points the leaf is weakened and the tissue eventually separates, thus forming open leaf cracks; also, in F, the enlargement of the cells of the chlorophyll-bearing bundle sheath on the right side of the large, vascular bundle. H and I, lesions where the open leaf crack has not fully developed, the constrictions being much deeper on the lower than on the upper leaf surface. A, B, C, D, E, F, G and I, × 95; H, × 190.



A



B

Fig. 6. A and B, enlargements of the sections shown in Fig. 5 of B and F, respectively.

Discussion

Symptoms similar to those described above were observed in 1931 on the variety Molokai 1575. At that time the leaf symptoms on Molokai 1575 resembled those of pokkah boeng disease of sugar cane, which is caused by the fungus *Fusarium moniliforme* Sheldon.

The leaf and stalk symptoms that developed on the cane varieties when grown in boron-free water cultures were in the majority of cases similar to the symptoms of pokkah boeng disease. Histological studies of the lesions, induced by omitting boron in the nutrient solutions, revealed no evidence of micro-organisms being present in the diseased tissue.

Since the symptoms of boron deficiency and those of pokkah boeng disease of sugar cane are in many respects similar, it is suggested that the severity of pokkah boeng disease might be associated with a boron deficiency in the sugar cane plant.

The role of boron in plant metabolism has not been definitely established. Boron is apparently essential for the normal development of those parts of the plant which are capable of making further growth. A degeneration of the growing parts of the plant takes place when a deficiency of boron occurs.

Summary

1. An abnormal growth resulted when sugar cane was grown in boron-free water cultures.

2. A normal growth was resumed when as little as .22 p. p. m. of boron was added to the nutrient solution.

3. A small amount of boron is essential for normal cane growth in water cultures.

4. The boron-deficiency symptoms developing on the cane plants were characterized by depressed growth, the development of distorted and chlorotic leaves and the presence of definite leaf and stalk lesions.

5. When cane plants were deprived of boron the meristematic or growing parts of the plants were seriously affected. If boron was not supplied to the nutrient solutions the plants soon died.

Acknowledgment

The writer wishes to express his appreciation to D. M. Weller for his assistance in relation to the histology of the problem and for the photomicrographs accompanying this paper.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
SEPTEMBER 18, 1933, TO DECEMBER 14, 1933.

Date		Per Pound	Per Ton	Remarks
Sept.	18, 1933	3.65¢	$73.00	Cubas.
"	19	3.62	72.40	Cubas.
"	20	3.62	72.40	Cubas.
"	25	3.60	72.00	Cubas.
"	27	3.59	71.80	Cubas.
"	28	3.56	71.20	Cubas, 3.57, 3.55.
"	29	3.53	70.60	Cubas.
Oct.	4	3.55	71.00	Cubas.
"	5	3.53	70.60	Cubas.
"	9	3.45	69.00	Cubas.
"	10	3.407	68.13	Cubas, 3.45, 3.40, 3.37.
"	13	3.34	66.80	Cubas, 3.35, 3.33
"	16	3.28	65.60	Cubas.
"	17	3.25	65.00	Cubas.
"	19	3.215	64.30	Philippines, 3.23; Cubas, 3.20.
"	27	3.30	66.00	Cubas.
Nov.	9	3.35	67.00	Cubas.
"	10	3.30	66.00	Cubas.
"	13	3.20	64.00	Cubas.
"	17	3.18	63.60	Philippines.
"	20	3.15	63.00	Cubas.
Dec.	4	3.27	65.40	Cubas.
"	5	3.275	65.50	Cubas, 3.25, 3.30.
"	11	3.23	64.60	Cubas.
"	14	3.19	63.80	Cubas.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVIII SECOND QUARTER, 1934 No. 2

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Soil Moisture and Sugar Cane:

The interrelation of soil moisture and the cane plant, dealt with heretofore in this journal on the basis of reporting special phases of study, is here handled as a practical review of the subject as a whole. The paper is one that will be welcomed by plantation men who have come to feel the need of apt information on this general subject.

New Cane Varieties:

A list is presented of new varieties that are considered worthy of spreading so that observations can be made on their performance on larger areas.

P.O.J. 2878 in the Factory:

A detailed account is given of the experimental use of clarification aids in handling refractory juices of the celebrated Java variety.

Phosphate Fixation:

A laboratory study presents in definite terms the varying degrees in which phosphates are held by Hawaiian soils. As an item in soil classification the determination of the phosphate fixing capacity gives promise of finding a useful place.

Costs that Relate to Mill By-products:

What does it cost to apply press-cake and molasses to the field? Some answers to this question are supplied from the plantations.

Grade "A" Requirements:

Field experiments under conditions of fluming present special difficulties. The problems of bundle weighing and taring have received special consideration and the minimum requirements for a Grade "A" status of accuracy are here set forth for the benefit of those whom they may concern.

The Juice Sampling Error Due to Wet Field Trash:

The error that attaches to flume water dilution of the first expressed juice has been painstakingly explored and a correction has been suggested.

The Parshall Flume:

A refinement in setting the flume is presented and explained.

The Industry in Mauritius:

A description of sugar production in Mauritius is taken from a French journal.

Soil Terminology:

Not only the layman and the agriculturist but the specialist as well is apt to find this comprehensive explanatory list of soil terms a valuable aid to his understanding of a great range of terms that have found their way into the language of those who have occasion to speak and write of soils.

Soil Moisture and the Sugar Cane Plant

By H. A. Wadsworth

Introduction

This short discussion of the local work in the relation of the sugar cane plant to soil moisture makes no claims for originality. The general conceptions upon which our present ideas are based and the experimental evidence which indicates the application of these conceptions to local conditions have been discussed in technical meetings of many sorts and reported in detail in *The Hawaiian Planters' Record* and other journals. It is perhaps unfortunate that although most of these reports have dealt with certain particular phases of a large general subject, the integration of these piecemeal studies into the general plan of investigation has apparently been slighted. The purpose of the present paper is to rectify this fault. It is purposely kept free of experimental detail, results only being reported, together with some expression of the significance of these results and the credence with which they may be accepted. References to the original work throughout the discussion may serve as an index to the literature and to the unpublished material in the project files of the Experiment Station, H. S. P. A. This list of references is not exhaustive; however, most of those mentioned carry citations which may be used to increase their scope.

Soils and Soil-Moisture Relationships

Soil moisture is ordinarily expressed as a percentage of the soil's oven-dry weight. Thus, if a sample of field soil when wet weighs 125 grams and after being oven dried to constant weight at 110° C., weighs 100 grams, the moisture content is reported as 25 per cent. Simple as this conception may be, we do not know how these 25 grams of easily liberated water were held when the soil was in the field. The English workers (8) would have us believe that the moisture was held in thin films around small inert grains of soil similar to small marbles or shot. More recently it has been suggested (21) that all the water in the soil under field conditions and with free drainage is colloidally bound, little or none being held in films around the grains. Some soils are so rich in materials, which may be readily hydrated (10), that it would appear that some moisture might occur in loose chemical combination at high moisture contents and be lost during the process of drying. Many attempts have been made to classify soil moisture with only indifferent success (11).

Regardless of the form in which this moisture occurs, the distribution of water through the soil after irrigation or after a rainfall is readily understood. The following more or less categorical statements summarize the results of several years' intensive study of soil moisture distribution:

(a) **When irrigation water is applied to a deep uniform soil it moves downward wetting each cubic inch of soil to a definite moisture content which is deter-**

mined by the nature of the soil. Uniform distribution is attained within a few hours after the water disappears from the surface (16).

(b) Subsequent movement of this soil moisture under the so-called "capillary forces" or by temperature effects is at such a slow rate that any such movement is insignificant as far as plants are concerned (1).

(c) Losses of soil moisture by evaporation from the soil surface after irrigation are limited to losses from the surface layer (16).

(d) Except for this minor loss of soil moisture by surface evaporation, moisture is lost from a soil mainly through the action of plant roots. The rate at which soil moisture is depleted in any area is a measure of the concentration of feeding roots within that area (6).

It should not be understood that the definite moisture content suggested in the statement (a) above is the same for all soils. Soils differ widely in their water-holding capacities, as everyone knows, but when this capacity is known the depth to which a given quantity of irrigation water will penetrate can be easily determined. An expeditious method of securing a reliable measure of the water-holding capacity of any soil is the moisture equivalent procedure (3), (20).

The Relation of the Cane Plant to Soil Moisture

The interest of the plantation man does not cease with getting the water into the soil; what happens to it is of equal importance. As has been indicated above, not much of this moisture is lost by surface evaporation. It remained, however, for Briggs and Shantz (4) to express the relation between the phenomena of wilt and soil moisture contents. These workers in 1912 announced that all plants, regardless of their botanical nature, showed signs of wilt at the same moisture content when those plants were grown on the same soil. This moisture content they called the "permanent wilting percentage." As might be expected, such an announcement raised a storm of protest, most of it originating in the Desert Laboratory at Tucson, Arizona. Here the observers seemed to feel that symptoms of wilt were more closely associated with the evaporating power of the atmosphere than any soil characteristic (5). The debate has died away in the last few years and one is left with the impression that the participants during the argument were not talking about the same thing. Recent substantiation in California (18) of the major premises of Briggs and Shantz, and locally (7), (14), (22) emphasizes the point that the permanent wilting percentage of a soil is one of its most important characteristics. The method for determining it has already been described (22).

The local work mentioned above focused interest upon a characteristic of the cane plant which had apparently escaped notice in keeping with its importance. This was that visible symptoms of wilt were not apparent with sugar cane until long after this point had been reached. There is no rolling of the leaves as with corn, nor any evident loss of turgidity of leaves as with sunflowers, nor is there any evident change in leaf color; but elongation ceases at about the same moisture content that resulted in these characteristic signs of wilt with other species (14). The fact that growth in the sugar cane continues at a uniform rate until the soil moisture is reduced to the permanent wilting percentage, after which it makes no significant further growth until water is added to the soil, is of greatest importance.

This proposition when added to the four which have been previously given furnishes a valuable guide to plantation practice as well as to field and pot experimentation.

Such a sweeping conclusion could not be accepted upon the basis of the results secured from a score of trials with small containers, although these results were in perfect accord with parallel but not identical results elsewhere (17), (19). Consequently, an elaborate system of large containers was established by means of which the conclusions of the pots studies might be verified not only for small plants but throughout the entire crop history from planting to harvest.

Fig. 1. This balance provided a means of measuring the daily uses of water by the plants in the tanks. Although of great capacity it was sensitive to about three pounds.

The physical equipment required for this work has been often described and the results reported in printed form and in the project file of the Experiment Station (13), (15). Briefly, the equipment consisted of fourteen large tanks, almost 6 feet high, and 28 inches in diameter. These tanks were uniformly filled with screened soil, of which the significant soil-moisture constants were known. When in place the tanks were set in long, deep trenches on either side of a concrete runway so that their tops were at the original ground level. A traveling crane on the concrete runway permitted the rapid and accurate weighing of the tanks, although each weighed more than a ton when ready for planting. In all cases the surface of the soil was protected from evaporation. Since the ever-increasing weight of the plant may be allowed for, it is evident that the gross weight of the tank is a measure of the average percentage of moisture in the tank, for water is

Fig. 2. Carefully grown plants were transplanted to the screened soil in the tanks. One of the evaporation screens is immediately behind the tank.

the only measurable variable in the system. In addition to a daily weighing of the tanks, the operations included the frequent measuring of length growth, total length being reported as the sum of lengths for all the stalks in the stool. Three views of the equipment used are given in Figs. 1, 2 and 3.

Some of the tanks were irrigated frequently so that a deficiency of water might never be experienced. Others were irrigated at longer intervals, while some were allowed to go so long between waterings that distinct signs of distress through water shortage were apparent. The results of these observations added one more general principle to those that have already been given:

> **Sugar cane grows normally over a wide range of soil moisture contents. Apparently growth is not retarded by deficient soil moisture until the wilting percentage for that soil is reached.**

It should be said that this finding is in perfect accord with similar work elsewhere, although length growth is rarely used as a measure of normal plant performance.

Figs. 4 and 5 illustrate the growth of cane and the consistent loss of weight, due to soil moisture utilization in two of the tanks. Fig. 4 gives the history of Tank 13 from July 6 to September 24. The scale on the right, to be used in conjunction with the upper curve, shows variations in weight. During the period

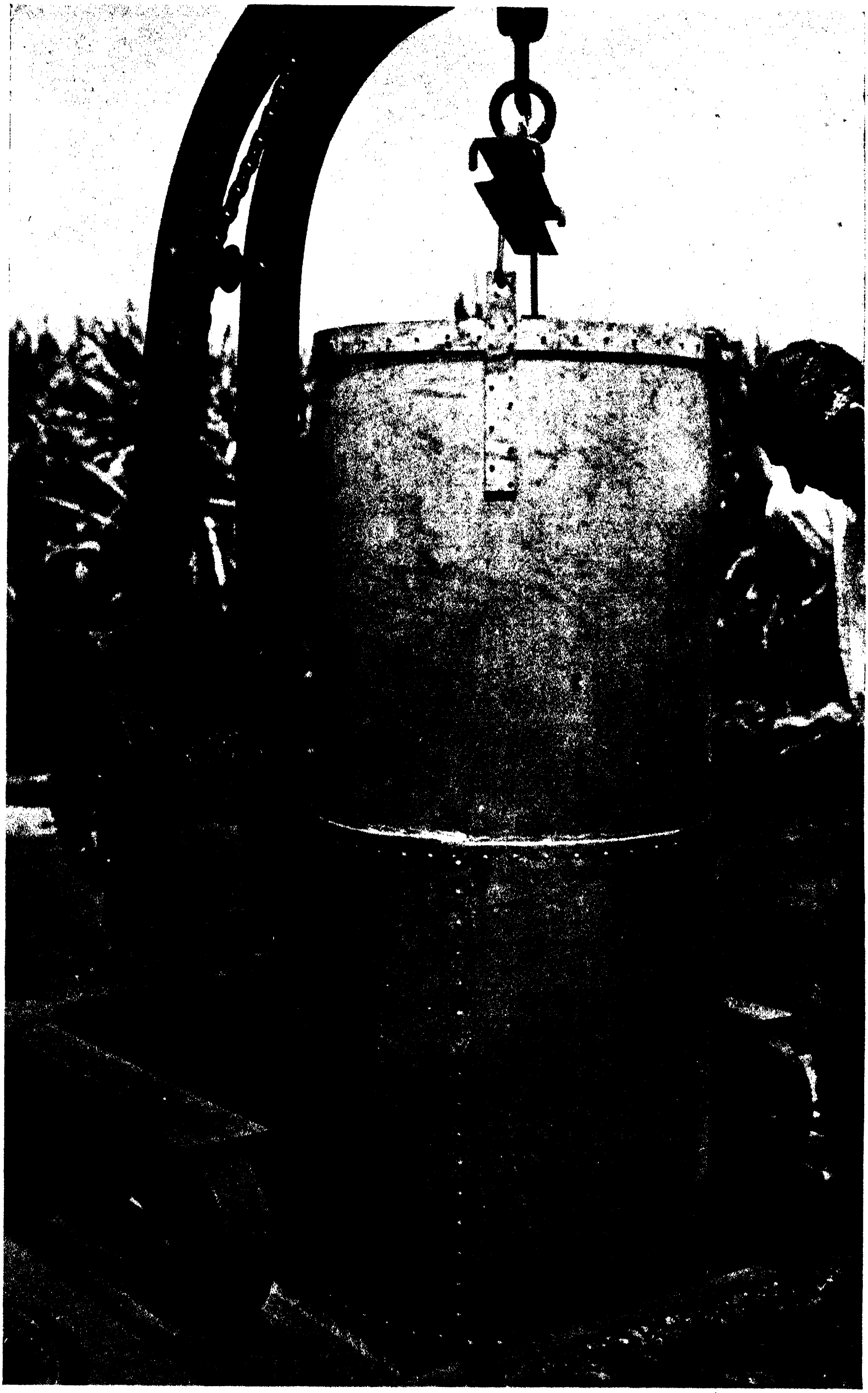

Fig. 3. One of the tanks used in the studies of the water relations of the sugar cane plant. Each tank weighed about one ton when ready for planting.

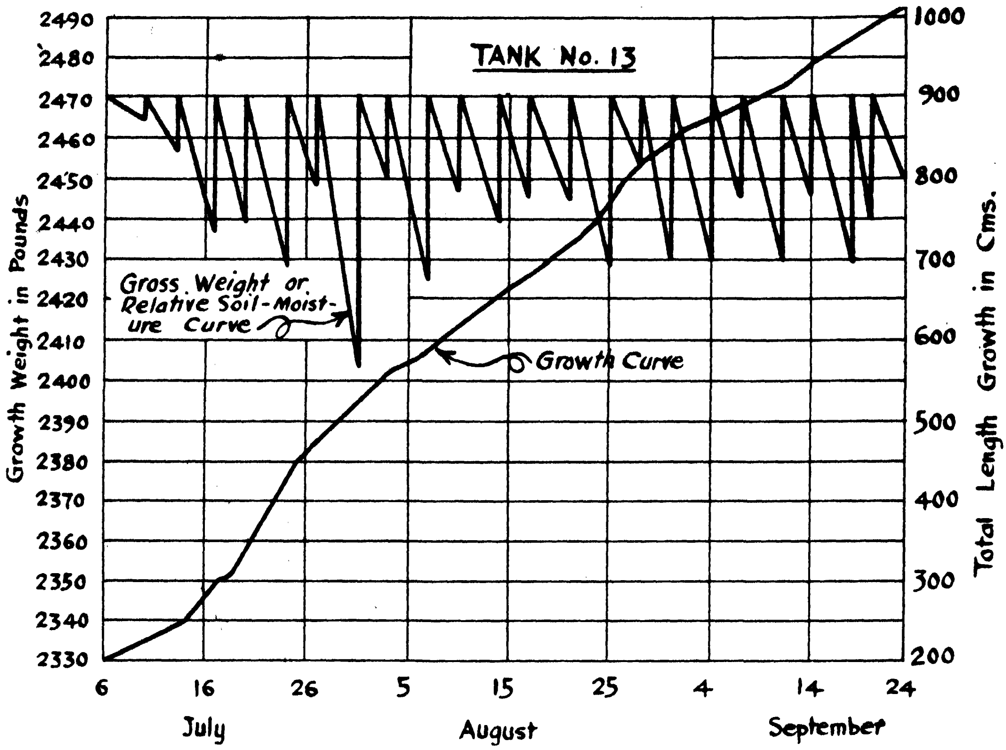

Fig. 4. Growth and soil-moisture history of Tank No. 13. Note the continuous growth of the cane and its independence of soil moisture. Frequent irrigations, as noted by the vertical jumps in the weight curve, kept the moisture above the wilting percentage.

in question the tank was irrigated 22 times, the average interval being about 3 days. It is evident that the vertical lines represent irrigations, since the adjusted gross weight can only increase with additions of water. The slope of the connecting lines indicates the rate at which water was lost between irrigations.

The lower curve, using the right-hand scale, is more significant, however. Here it is seen that length-growth proceeded uniformly and almost regularly from July 6 to September 25. Evidently soil moisture played no part in determining the rate of growth. The minor departures of this line from being perfectly straight are probably caused by variations in temperature.

Quite a different picture is shown in Fig. 5. Tank 4 was allowed to suffer due to a deficiency of soil moisture, the tank being irrigated only 6 times during the same interval. Here the growth curve shows the influence of this deficiency. Getting off to a good start on July 6, the plant grew uniformly until July 14, when it ceased growth and made no more until July 25, the date of the next irrigation. Growth was resumed at once and proceeded normally until August 3, when, after a short transition, growth once more ceased. The fact that in all cases growth is resumed after an irrigation demonstrates that the stopping of growth is due to a deficiency of soil moisture.

It is interesting to note, moreover, that while the cane is growing the rate of growth is about constant for the period during which soil moisture is available; nor does the plant seem to suffer any handicap because of the period of no growth which it may have experienced.

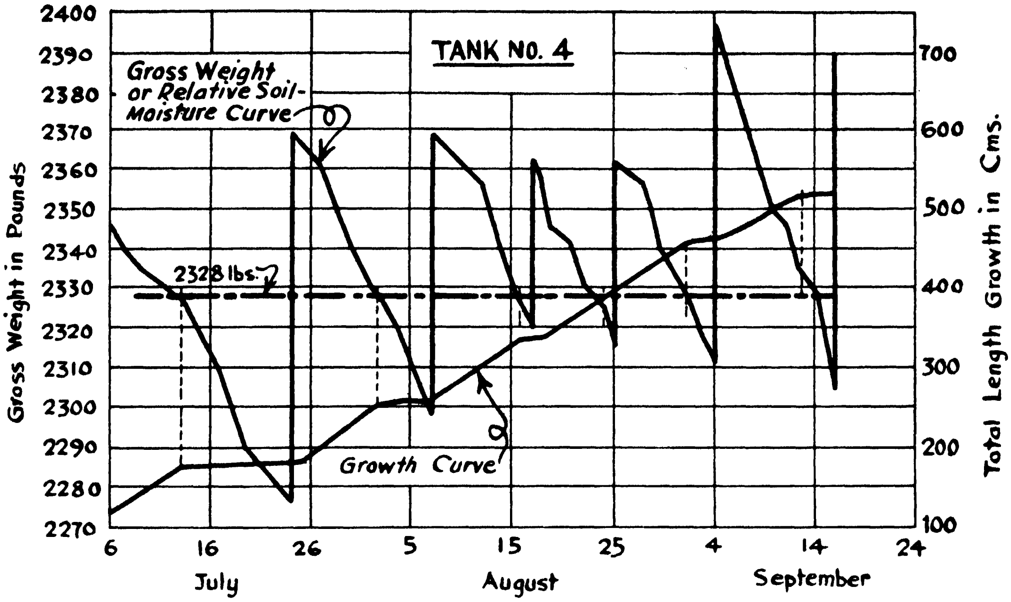

Fig. 5. Growth and soil-moisture history of Tank No. 4. Here the growth is not continuous as in Tank No. 13, but is made up of periods of normal growth and periods of little or no growth. Growth stopped in all cases when the tank weighed 2328 pounds. At this weight the moisture in the soil in the root zone was the wilting point.

Moreover, as indicated in the figure, growth in all cases stopped when the gross weight of the system had dropped to 2,328 pounds. Subsequent observations indicated that the moisture content in the soil in the upper 30 inches in Tank 4 was at the wilting point when the gross weight of the tank had been reduced to 2,328 pounds by the activity of the cane roots.

If the results of these tank studies may be taken as significant (and their similarity to other findings gives support), several far-reaching conclusions may be reached:

(a) There seems to be no advantage in irrigating more frequently than is necessary to keep the cane growing.
(b) If the irrigation interval is greater than that necessary to keep the cane growing, growing time is lost; such a loss of growth is not made up by unusual activity when water is applied.

That these conclusions, reached by a study of isolated cane plants in tanks, are applicable to field conditions, is demonstrated by elaborate studies of plant and water relations on the mainland (9) and by Shaw's (12) comprehensive Field F experiment at Waipio. Similar results have been obtained by Shaw under plantation conditions at the Waialua Agricultural Company.

Water Absorption by the Cane Plant (23)

An additional point of interest with respect to the characteristics of the cane plant was its apparent capacity for absorbing water by its above-ground parts during showers, the conveyance of the water into the roots and its discharge through the roots into the soil. During the early stages of the investigation it was fre-

quently noted that gains of weight in the tanks occurred during showers of rain. Since the most evident reason for this gain was a leaking of water through the seals around the cane sticks, these seals were continually improved as experience was gained. The gains in weight under natural showers and sprinkling continued. The most spectacular case was one in which a gain of 80 pounds was observed after three hours of garden hose sprinkling. In this case the seal was composed of asphalt applied hot in a layer three inches deep over the board covers. When the hose was played on the critical parts of this seal for two hours, no gain of weight was apparent. Moreover, the soil-moisture content in depths six inches below the soil surface was considerably increased; the surface layer of soil was at practically the same moisture content after sprinkling as before.

No explanation which satisfies all the observed conditions has been offered, although Breazeale (2) and others suggest that such absorption and conveyance may take place. In Breazeale's work, the soil involved is extremely dry and the quantities of water moved are small.

It would appear, however, that light rains or showers might have more effect on the cane's well-being than is ordinarily assumed. The problems involved in the study of the conditions necessary for this absorption are of compelling scientific interest as well as of possible commercial importance.

Future Studies

It will be noted that the work reported so far has to do with the formation of cane and not the formation of sugar. A study of the role of soil moisture in cane ripening forms the next logical step in the investigations. General plantation procedure demands the drying-off of a field for some time prior to harvest. Although it is probably true that such a practice improves the quality ratio by drying out the sticks and concentrating the juice, it is by no means clear that additional sucrose is manufactured during this period. Studies with other crops (9), (16) indicate that such important properties as the sugar content of prunes and the drying ratio of peaches is quite independent of the soil moisture content upon which the crops were grown, provided the wilting percentage is not reached.

Drying out a field prior to harvest has unquestionable value in reducing the tonnage of cane that has to be handled per ton of sugar. But such a saving can only be at the expense of growing time. We need more basic information with respect to the effect of soil moisture upon sugar formation before harvesting and milling costs can be balanced against the potential sugar-producing value of the time which is lost by drying off.

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Seedlings for Spreading

The problem of choosing a few seedlings from the many seedlings under trial on plantations for rapid multiplication resolves itself into the degree of confidence we may have in a seedling after seeing its performance in a number of places.

This may be simply expressed by designating those canes which show exceptional worth through observation and preliminary yield data as "ten-acre" canes. In these cases it would seem advisable to extend the canes to approximately ten acres before waiting for yield data from experiments. A second designation of "one-acre" canes would be in order. These would include the seedlings on which the early information was outstanding, but on which insufficient yield data are available at the present time to suggest further expansion. With one acre of a promising seedling planted the stage is then set for a rapid expansion to ten acres or more and to final variety tests should the information continue favorable.

The following list of seedlings are classified according to the above-mentioned scheme.

"TEN-ACRE" SEEDLINGS

H 109 Conditions:

28-1234	(POJ 2364 x 26 C 270)
31-1389	(POJ 2878 x 26 C 270)

Windward Kauai:

Middle Belt Irrigated Lands:	Co. 213	(POJ 213 x Kansar)
	27-3840	(Badila x H 456)
	28-2055	(POJ 2364 x 26 C 270)
Makai Lands:	28-2055	(POJ 2364 x 26 C 270)
	31-1389	(POJ 2878 x 26 C 270)

Hilo District:

Mauka:	Co. 213	(POJ 213 x Kansar)
	Co. 290	(Co. 221 x D 74)
	28-1234	(POJ 2364 x 26 C 270)
	29-3859	(H. Uba x H 456)
Makai:	28-1234	(POJ 2364 x 26 C 270)
	31-1389	(POJ 2878 x 26 C 270)

Hamakua and Kohala Districts:

Mauka:	Co. 213	(POJ 213 x Kansar)
	U. S. 996	(Kassoer)
Middle Belt:	Co. 290	(Co. 221 x D 74)
	28-1234	(POJ 2364 x 26 C 270)
	29-3859	(H. Uba x H 456)
Makai:	28-1234	(POJ 2364 x 26 C 270)
	28-1864	(POJ 2364 x 26 C 270)
	31-1389	(POJ 2878 x 26 C 270)

"ONE-ACRE" SEEDLINGS

H 109 Conditions—Short Cropping:

28-597	(POJ 2364 x D 1135)	
893	(POJ 2364 x 26 C 270)	for non-eye spot areas
1095	(POJ 2364 x D 1135)	
1205	(POJ 2364 x 26 C 270)	for non-eye spot areas
1821	(POJ 2364 x Wailuku 11)	
1864	(POJ 2364 x 26 C 270)	for non-eye spot areas
1931	(POJ 2364 x 26 C 270)	
2014	(POJ 2364 x 26 C 270)	
2055	(POJ 2364 x 26 C 270)	
2096	(POJ 2364 x 26 C 270)	
5468	(Str. Mex. x Kohala 73)	
29-791	(POJ 2364 x Manoa 301)	for non-eye spot areas
6334	(POJ 2364 x 20 S 16)	
7273	(POJ 2725 x H 227)	
7788	(28-1227 x H 456)	
30-748	(POJ 2364 x 26 C 113)	

H 109 Conditions:

28-985	(POJ 2364 x D 1135)
2014	(POJ 2364 x 26 C 270)
2055	(POJ 2364 x 26 C 270)
2694	(Yel. Cal. x H 109)
5934	(Yel. Cal. x H 109)
29-6334	(POJ 2364 x 20 S 16)
30-453	(POJ 2364 x Ewa 569)
2417	(28-674 x H 456)
7353	(POJ 2364 x Mak. 3)
31-1236	(POJ 2878 x Cavengerie)
1402	(POJ 2878 x H 9811)
2058	(H 9806 x POJ 2878)
2538	(POJ 2878 x H 7878)
3012	(POJ 2364 x 26 C 270)
3016	(POJ 2364 x 26 C 270)
3040	(POJ 2364 x 27 C 518)

H 109 Conditions—Eye Spot Resistant Canes:

26 C 270	(Yel. Cal. x H 109)
28-2055	(POJ 2364 x 26 C 270)
3540	(Yel. Cal. x H 109)
30-2417	(28-674 x H 456)
4422	(POJ 2364 x H 8988)
31-626	(28-4898 x POJ 2878)
2343	(28-4772 x POJ 2878)
2346	(28-4772 x POJ 2878)
3012	(POJ 2364 x 26 C 270)

Windward Kauai:

Mauka—Middle—Irrigated:

Hawi 10	(Badila x D 1135)
28-1813	(POJ 213 x H 456)
4515	(H. Uba x H 456)

4731	(H. Uba x H 456)
4803	(N. Uba x H 456)
4830	(N. Uba x H 456)
29-3656	(Kassoer x H 9812)
7989	(Kassoer x H 9812)
8045	(POJ 2364 x D 117)
30-4422	(POJ 2364 x H 8988)
31-616	(28-4898 x POJ 2878)
624	(28-4898 x POJ 2878)
701	(N. Uba x POJ 2878)
728	(N. Uba x POJ 2878)
1389	(POJ 2878 x 26 C 270)
2343	(28-4772 x POJ 2878)
2346	(28-4772 x POJ 2878)
2482	(POJ 2878 x Manoa 301)
2563	(POJ 2878 x H 109)

Kauai:

Mauka—Unirrigated:

Co. 213	(POJ 213 x Kansar)
27-3840	(Badila x H 456)
28-2055	(POJ 2364 x 26 C 270)
2321	(Uba x H 456)
4291	(H. Uba x H 456)
4399	(H. Uba x H 456)
4456	(H. Uba x H 456)
4515	(H. Uba x H 456)
4567	(H. Uba x H 456)
4731	(H. Uba x H 456)
29-3614	(Kassoer x H 9812)
3656	(Kassoer x H 9812)
7989	(Kassoer x H 9812)
8045	(POJ 2364 x D 117)
30-3622	(N. Uba x Waialua 8)
31-135	(POJ 2878 x 27-994)
616	(28-4898 x POJ 2878)
701	(N. Uba x POJ 2878)
728	(N. Uba x POJ 2878)
2346	(28-4772 x POJ 2878)

Makai Irrigated:

29-8045	(POJ 2364 x D 117)
30-748	(POJ 2364 x 26 C 113)
2417	(28-674 x H 456)
4422	(POJ 2364 x H 8988)
7353	(POJ 2364 x Mak. 3)
31-1236	(POJ 2878 x Cavengerie)
2343	(28-4772 x POJ 2878)
2346	(28-4472 x POJ 2878)
2482	(POJ 2878 x Manoa 301)
2563	(POJ 2878 x H 109)

Hilo Mauka:

28-1813	(POJ 213 x H 456)
2014	(POJ 2364 x 26 C 270)

2321	(Uba x H 456)
4291	(H. Uba x H 456)
4399	(H. Uba x H 456)
4501	(H. Uba x H 456)
4594	(H. Uba x H 456)
4649	(H. Uba x H 456)
4731	(H. Uba x H 456)
4830	(N. Uba x H 456)
4867	(N. Uba x H 456)
29-3290	(H. Uba x H 456 or D 1135)
3656	(Kassoer x H 9812)
3880	(H. Uba x H 456)
3884	(H. Uba x H 456)
30 H.P. 78	(POJ 2364 x Aiea 165)
31-624	(28-4898 x POJ 2878)
701	(N. Uba x POJ 2878)
2346	(28-4772 x POJ 2878)
2482	(POJ 2878 x Manoa 301)

Hilo Makai:

Co. 290	(Co. 221 x D 74)
28-4731	(H. Uba x H 456)
29-3859	(H. Uba x H 456)
8045	(POJ 2364 x D 117)
8053	(POJ 2364 x D 117)
30-453	(POJ 2364 x Ewa 569)
7353	(POJ 2364 x Mak. 3)
30 H.P. 76	(POJ 2364 x Aiea 165)
78	(POJ 2364 x Aiea 165)
182	(POJ 2364 x H 227)
31-1203	(POJ 2878 x D 117)
2343	(28-4772 x POJ 2878)
2346	(28-4772 x POJ 2878)
2482	(POJ 2878 x Manoa 301)

Hamakua & Kohala:

Mauka—Elevation 1400 ft. up:

Co. 290	(Co. 221 x D 74)
28-2321	(Uba x H 456)
4291	(H. Uba x H 456)
4370	(H. Uba x H 456)
4461	(H. Uba x H 456)
4867	(N. Uba x H 456)
4908	(H. Uba x H 456)
29-3290	(H. Uba x H 456 or D 1135)
3656	(Kassoer x H 9812)
3859	(H. Uba x H 456)
3880	(H. Uba x H 456)
3884	(H. Uba x H 456)
7989	(Kassoer x H 9812)
30-4192	(Uba x K 107)
31-135	(POJ 2878 x 27-994)
624	(28-4898 x POJ 2878)
701	(N. Uba x POJ 2878)

Middle—Elevation 800-1400 ft.:

Co. 213	(POJ 213 x Kansar)
28-1813	(POJ 213 x H 456)
1864	(POJ 2364 x 26 C 270)
2014	(POJ 2364 x 26 C 270)
2055	(POJ 2364 x 26 C 270)
28-4515	(H. Uba x H 456)
4639	(H. Uba x H 456)
4649	(H. Uba x H 456)
4731	(H. Uba x H 456)
4803	(N. Uba x H 456)
4830	(N. Uba x H 456)
4874	(N. Uba x H 456)
5366	(U.D. 23 x Badila)
29-791	(POJ 2364 x Manoa 301)
3207	(H. Uba x H 456 or D 1135)
3290	(H. Uba x H 456 or D 1135)
3656	(Kassoer x H 9812)
3880	(H. Uba x H 456)
3884	(H. Uba x H 456)
7617	(20 M.P. 60407 x 25 C 34)
7989	(Kassoer x H 9812)
8045	(POJ 2364 x D 117)
8053	(POJ 2364 x D 117)
30-453	(POJ 2364 x Ewa 569)
2417	(28-674 x H 456)
4192	(Uba x K 107)
31-624	(28-4898 x POJ 2878)
701	(N. Uba x POJ 2878)
728	(N. Uba x POJ 2878)
2346	(28-4772 x POJ 2878)

Makai—Elevation 0-800 ft.:

28-1095	(POJ 2364 x D 1135)
1813	(POJ 213 x H 456)
2014	(POJ 2364 x 26 C 270)
2055	(POJ 2364 x 26 C 270)
4830	(N. Uba x H 456)
29-3290	(H. Uba x H 456 or D 1135)
3859	(H. Uba x H 456)
7617	(20 M.P. 60407 x 25 C 34)
7788	(28-1227 x H 456)
8045	(POJ 2364 x D 117)
8053	(POJ 2364 x D 117)
30-453	(POJ 2364 x Ewa 569)
2417	(28-674 x H 456)
30 H.P. 78	(POJ 2364 x Aiea 165)
31-701	(N. Uba x POJ 2878)
1236	(POJ 2878 x Cavengerie)
1389	(POJ 2878 x 26 C 270)
2343	(28-4772 x POJ 2878)
2346	(28-4772 x POJ 2878)
2347	(28-4772 x POJ 2878)

Kohala Makai—Short Cropping Varieties:

28-597	(POJ 2364 x D 1135)
893	(POJ 2364 x 26 C 270)
1095	(POJ 2364 x D 1135)
1188	(POJ 2364 x 26 C 270)
1205	(POJ 2364 x 26 C 270)
2014	(POJ 2364 x 26 C 270)
5468	(Str. Mex. x Kohala 73)
29-1570	(POJ 2364 x 26 C 148)
6334	(POJ 2364 x 20 S 16)
7273	(POJ 2725 x H 227)
7617	(20 M.P. 60407 x 25 C 34)
8045	(POJ 2364 x D 117)
8053	(POJ 2364 x D 117)
30-453	(POJ 2364 x Ewa 569)
748	(POJ 2364 x 26 C 113)
30 H.P. 78	(POJ 2364 x Aiea 165)
31-1203	(POJ 2878 x D 117)
1236	(POJ 2878 x Cavengerie)
1389	(POJ 2878 x 26 C 270)
2346	(28-4772 x POJ 2878)
2347	(28-4772 x POJ 2878)
2563	(POJ 2878 x H 109)
3024	(POJ 2364 x 27 C 445)

Hamakua & Kohala—Poor Knoll Canes:

U.S. 996	(Kassoer)
28-4291	(H. Uba x H 456)
29-8510	(U.S. 666 x Self)

A. J. M.
C. G. L.

Manufacturing Qualities of P. O. J. 2878*

By H. F. Hadfield

A request from the Experiment Station, H. S. P. A., Honolulu, for a sample of sugar boiled entirely from an "A" strike of P.O.J. 2878 cane in order to compare its refining qualities with sugar boiled from Yellow Caledonia and other canes, was the incentive to make a few experiments on the qualities of the juice from this cane when crushed alone, as several factories reported its clarifying qualities to be poorer than that of Yellow Caledonia and other canes.

Therefore, on Saturday, February 24, a preliminary four-hour run was made with P. O. J. 2878 alone and the clarifying qualities studied, the juice being treated in the regular way, that is, heated from 212°-216° F. at pH 8.0-8.3.

Several weeks prior to this test, P.O.J. 2878 had been flumed into the mill mixed with Yellow Cadelonia and P.O.J. 36 in the proportion of 25-30 per cent. Under these conditions no difficulty was found in the clarifying qualities of the juice, although the press cake was not quite so porous as usual and at intervals was "sloppy" and the pol higher.

Under ordinary conditions Yellow Caledonia and other canes would clarify in about 45 minutes, with a turbidity reading of 3.5-4.0 cm. When P.O.J. 2878 was crushed alone, however, and limed to pH 8.0-8.3 in the ordinary way, instead of clarifying in 45 minutes at a turbidity reading of 3.5-4.0 cm., it took 2 hours and 28 minutes to settle at a turbidity reading of 2.6 cm. Under these conditions the tonnage of cane per hour had to be reduced and the mills had to shut down in order to clear the settling tanks. During this clarifying test the following data were recorded:

Crusher Juice	Brix	16.59		16.66		17.66	
	Pol	14.89		14.80		16.09	
	App. Pur.	89.75		88.83		91.11	
Mixed Juice	Brix	13.59		13.96		14.34	
	Pol	11.92		12.36		12.83	
	App. Pur.	87.71		88.54		89.47	
	pH	8.8		9.2		8.4	
Last Mill Juice	Brix	3.10		3.30		3.68	
	Pol	2.45		2.52		2.74	
	App. Pur.	79.03		76.36		74.46	
Clarified Juice	Brix	13.44	13.91	13.90	13.88	14.31	14.01
	Pol	11.64	12.29	12.36	12.34	12.76	12.51
	App. Pur.	86.61	88.35	88.92	88.90	89.17	89.29
	pH	7.5	7.9	7.4	7.9	7.8	7.9
	Turbidity, cm.	2.6	2.8	2.0	2.3	2.8	2.6

* A report presented at the Hilo meeting of the A. H. S. T., 1934, through the courtesy of Alex Fraser, Manager of Hilo Sugar Company.

Press Juice	Brix	13.81
	Pol	12.09
	App. Pur.	87.54
	pH	8.5
	Turbidity, cm.	4.0
Press Cake	Pol	4.2
	Bagasse per 100 solids in cake 22.43%.	
Bagasse	Pol	1.08
	Pol	1.39
	Moisture	39.0
	Moisture	43.0
Fiber % Net Cane		11.00%
		10.00%

As it required about a twelve-hour run to clear the factory of Yellow Caledonia juice, etc., in order to boil with certainty an "A" strike of P.O.J. 2878 alone, arrangements were made to flume this cane on Tuesday, February 27. W. L. McCleery, Acting Sugar Technologist of the Experiment Station, H. S. P. A., very kindly consented to be present, and plans were made to make the following experiments:

Condition at the Settlers With P.O.J. 2878 Juice Alone

During the early hours of Tuesday morning, the tonnage of cane per hour was reduced, and six settlers out of thirteen and five presses out of ten were cleaned in preparation for this experiment. At 5:30 a. m. the fluming of P.O.J 2878 alone started. At 8:30 a. m. the six settlers had filled and it was necessary to close the mills down after only a three-hour run. During the rest of the twelve-hour day stops had to be made at intervals amounting to 4 hours and 50 minutes, the tonnage averaging 38.5 per hour.

Experiment 1.

Period of settling—regular practice. Heating 212-216° F., liming 8.0-8.3 pH.

Settler No. 5

Time to fill	7	minutes.
Cold juice pH	8.3	
Clarified juice pH	7.7	
Turbidity, cm.	1.0	after 45 minutes settling.
Cold juice pH	8.3	
Clarified juice pH	7.7	
Turbidity, cm.	1.1	after 55 minutes settling.
Cold juice pH	8.3	
Clarified juice pH	7.7	
Turbidity, cm.	1.5	after 75 minutes settling.
Cold juice pH	8.3	
Clarified juice pH	7.7	
Turbidity, cm.	1 9	after 90 minutes settling.

Experiment 2.

Period of settling—irregular practice.

Dividing the application of lime into two parts: First at 6 pH before heating

and made up to pH 8.3 later; second at 7 pH before heating and made up to pH 8.4 later by adding lime to the settling tanks.

Settler No. 11

Cold juice before heating..........	6.0 pH
Clarified juice after heating........	8.3 pH
Turbidity, cm.	1.5 after 1-1½ hours settling.

Settler No. 12

Cold juice before heating..........	6.0 pH
Clarified juice after heating........	8.4 pH
Turbidity, cm.	1.5 after 1-1½ hours settling.

Settler No. 10

Cold juice before heating..........	7.0 pH
Clarified juice after heating........	8.3 pH
Turbidity, cm.	2.0 after 1-1½ hours settling.

Settler No. 11

Cold juice before heating..........	7.0 pH
Clarified juice after heating........	8.0 pH
Turbidity, cm.	1.5 after 1-1½ hours settling.

In all four cases the volume of settlings prevented the opening of the lower juice valve into the clear flume line to the evaporators.

Experiment 3—Double Superphosphate as a Clarifying Agent.

In this experiment 5-, 10- and 15-pound portions of double superphosphate were added (in Settlers Nos. 12, 13 and 1 respectively) to the juice with the liming and heating under regular practice.

Settler No. 12		**Five Lbs. D. S. Phos.**
Cold Juice	8.3 pH	
Hot limed juice	8.0 pH	Before phos. was added.
Clarified juice	7.6 pH	After phos. was added.
Turbidity	1.4 cm.	After 55 min. settling.

Settler No. 13		**Ten Lbs. D. S. Phos.**
Cold juice	8.3 pH	
Hot limed juice	8.0 pH	Before phos. was added.
Clarified juice	7.5 pH	After phos. was added.
Turbidity	1.7 cm.	After 47 min. settling.

It was necessary to add a little more lime after the addition of phosphate to increase the pH to 7.5.

Settler No. 1		**Fifteen Lbs. Phos.**
Cold juice	8.3 pH	
Hot limed juice..................	7.8 pH	Before phos. was added.
Clarified juice	7.2 pH	After phos. was added.
Turbidity	1.5 cm.	After 45 min. settling.

It was necessary to add a little more lime after the addition of phosphate to increase the pH to 7.2.

In all three cases the volume of settlings prevented the opening of the lower valve into the clear flume line to the evaporators.

Experiment 4—Addition of Bagasse Screenings to the Juice after Liming and Heating in the Ordinary Way.

Screenings were added slowly into the settling tank as it filled with the juice.

Cold juice	8.3 pH
Clarified juice	7.8 pH
Turbidity	1.0 cm.

The juice was cloudy and a great deal of the bagasse screenings would not settle and floated to the top. Juice from the second valve was very dark and the bagasse screenings did not carry the impurities to the bottom.

During these tests the following data were recorded for the twelve-hour run on P.O.J. 2878 alone:

Crusher Juice	Brix	16.72
	Pol	14.92
	App. Pur.	89.23
Mixed Juice	Brix	13.34
	Pol	11.69
	App. Pur.	87.63

Suspended solids in juice 0.229, 0.176, 0.167, 0.218.

Average 0.197

Last Mill Juice	Brix	3.50
	Pol	2.49
	App. Pur.	71.14
Bagasse	Pol	1.22
	Sol. non-sugars	0.495
	Moisture	41.21
	Fiber %	57.075
	Bag. % cane	20.64
	Extraction	98.06
Fiber % Net Cane	10.00%	
	12.00	
Dilution	26.61% N. J.	
Cane Ratio	8.12	
Quality Ratio	8.85	
Field Trash	2.00% approximately.	
Ab. Juice Factor	101	

Experiment 5—Presses.

During the tests on clarification, tests were also made at the presses on the settlings with bagasse screenings.

No. 6 Press—Without bagasse screenings on P. O. J. 2878 settlings alone:

Pol of cake	7.4	5.9
Moisture of cake	76.8	82.00

Per cent bagasse per 100 solids 20.69 and 26.29.

Press cake very sloppy.

No. 3 Press—With 5 lbs. bagasse screenings per settler.
(Capacity of settler 270 cubic feet.)

Pol of cake	3.0	3.7
Moisture of cake	85.1	85.88

Per cent bagasse per 100 solids 34.59 and 33.54.
Press cake sloppy.

Experiment 6—Sugar.

Grain was small.
Strike "A" grained (without seed).
Color lighter than usual.
Pol 98.3.
No purging.
Ash 0.28 per cent.
Per cent suspended solids 0.046.

SUMMARY

The tests seemed to indicate that:

1. To divide the application of lime before and after heating is beneficial in the settling of juices, but the volume of settlings was so great that the juice from the lower valve of the settling tank was never clear.

2. To add double superphosphate to the limed juice is beneficial in settling the juice and gave a lighter color than in the case of the test where the application of lime was divided. The volume of settlings, however, was the same, and the juice from the lower valve of the settling tank was never clear.

3. The addition of bagasse screenings to the juice in the settlers was not beneficial from the clarification standpoint. Fine bagasse added to the settlings just prior to filtration materially reduced pol in cake.

4. When P.O.J. 2878 was crushed alone, the juice required, after liming and heating in the ordinary way, over one hour to clarify to a very poor turbidity of 1.5 cm.

5. When P.O.J. 2878 is mixed with other canes such as Yellow Caledonia and P.O.J. 36 in the proportion of 25 to 30 per cent, clarification is just as good as that of Yellow Caledonia or P.O.J. 36 alone. The presses, however, do not function as well, and though the press cake is fairly firm the pol is usually higher.

Phosphate Fixation in Hawaiian Soils — II

By Arthur Ayres

The first of a series of papers (2) on the subject of phosphate fixation appeared under the above title in a recent issue of this publication. It is the plan of the author, Francis E. Hance, to have succeeding papers presented by members of the staff as their researches become available for publication. The following presentation constitutes the second paper of this series.

The recognized importance of the phenomenon of phosphate fixation to agriculture has led, in recent years, to world-wide investigation of the subject. That greater unity of thought does not exist among the numerous investigators as to the precise nature of the chemical processes involved is due in part to the greatly diverse soil types available for study. Many constituents of a soil are capable of rendering phosphates insoluble. Considered individually, certain of the reactions by which fixation takes place are understood, while others remain relatively obscure. The complexity of the problem lies essentially in the fact that fixation by such a heterogeneous mixture as a soil involves simultaneously a large number of reactions, both physical and chemical, which occur at different rates and in widely varying degree in different soils.

Until very recent years the subject of fixation of phosphates by soils had received practically no attention at this Station. That fixation occurs in Hawaiian soils, however, and that something of the extent to which it occurs were realized, at least as early as 1902, is evidenced by a publication of that date by J. T. Crawley (1). Twenty years later, McGeorge (3) showed that phosphates were susceptible to fixation by Hawaiian soils from dilute solutions of acids and bases. Absorption from weak solutions of various acids was further studied in this laboratory by R. R. Ward and P. L. Gow in connection with their investigation of the Demolon and Barbier method of soil phosphate evaluation. At the present time various aspects of the problem are being investigated by L. E. Davis and the writer, as indicated by Hance (2) in a recent issue of *The Hawaiian Planters' Record*.

A phase of the general study which is of particular importance in Hawaii is that of the extent to which fixation of phosphates occurs in the many and varied soil types comprising our agricultural lands. Numerous Hawaiian soils, although admittedly deficient in available phosphates as indicated by crop response to this nutrient, nevertheless fail to show improved yields following moderate applications of soluble phosphatic fertilizers. Yet, the fertility of these same soils may be definitely enhanced through the addition of phosphate in amounts greatly in excess of current crop requirements. However, the failure to obtain response to moderate treatments of phosphate on areas deficient in this nutrient does not necessarily indicate high fixation. It therefore becomes a matter of very practical importance to know whether the failure of the cane crop to respond to normal applications of phosphate, on phosphate deficient areas, is due to excessive fixation or to some other

limiting factor. Much can be accomplished in this direction through correlating the fixing power of the soils with the observations of agriculturists relative to response to phosphate fertilization under field conditions. Such a study involves first, the development of a satisfactory laboratory method for measuring fixation; and, second, an investigation of the extent to which fixation occurs. It is the purpose of this paper to present the results of inquiry into these and closely related matters.

EXPERIMENTAL

The opinions of investigators have differed as to the most satisfactory means of determining the ability of a soil to fix phosphates. A device which has been used for this purpose consists in the percolation of a phosphate solution of known concentration through a column of soil and subsequent analysis of the percolate. Another procedure involves agitation of the soil with a solution of phosphate, the extent of fixation being calculated from the initial and final concentrations of phosphate in the solution. A third method employed to the same end consists in intimately mixing the desired amount of a soluble phosphate with a given weight of soil and maintaining the mixture in a moist condition for a period of time sufficient to effect fixation. In the last case the unfixed phosphate is removed from the mixture for determination either by extraction or by dialysis. The absorbed phosphate in all of these methods is measured indirectly, that is, as the difference between the quantity added to the soil and the amount remaining unfixed at the end of a given period. Certain procedures are better suited than others to the investigation of a particular phase of the subject. For the study in hand, involving the evaluation of a relatively large number of soils, a method has been developed in this laboratory which consists basically in the mechanical agitation of the soil-phosphate solution mixture for a definite period, followed by filtration under gravity and subsequent analysis of the filtrate.

Much of the work which has been done on fixation has involved absorption of the phosphate from weak solutions of acids. In order to more nearly simulate the conditions under which fixation occurs in the field the reactions in the present investigation were brought about in solutions of approximate neutrality.

The nature of many Hawaiian soils is such that when suspended in neutral solutions of very low electrolyte content filtration is extremely difficult. In such cases the task of effecting a separation of the solution from the soil becomes a very laborious and greatly protracted one, even when recourse is had to filtration under suction, or to the Chamberland (porcelain) filter utilizing a pressure of one hundred pounds per square inch. Dialysis likewise is a very slow process and not well suited to the present work. However, this difficulty was overcome by the use of an electrolyte (ammonium chloride) in amount equal to one per cent by weight of the phosphate solution. In the resulting flocculation the highly dispersed soil particles are rendered incapable either of passing through the filter or of preventing the passage of the solution. A partial and desirable precipitation of colloidal organic matter also results from the presence of the salt. Ammonium chloride increases somewhat the absorption of phosphate by our soils. This observation, which is of interest in view of the extensive use by the plantations of similar salts as sources of

plant nutrients, will be investigated in the near future; doubtless it is brought about in part through the mechanism of base exchange. While, as stated, this substance tends to increase the fixation of phosphate, it is not felt that its use in this work detracts from the value or significance of the results, the essential purpose of which is to show the relationship of one soil to another with respect to fixation. Furthermore, the same effect is no doubt obtained, although probably in lesser degree, under actual field conditions.

The phosphate solutions employed in the study were prepared from diammonium phosphate and ammonium chloride. Prior to extraction by the soil the acidity of all solutions used was adjusted with hydrochloric acid to a point just under neutrality (pH = 6.8). Preparation of the soils consisted in air drying, pulverizing, and passing through a 2 mm. screen. Extraction was accomplished by continuous agitation of the soil and phosphate solution mixture (ratio = 1:10) for a period of 24 hours. Immediately following this operation a portion of the solution sufficient for analysis was filtered off. The first portion of the filtrate was discarded in order to preclude the possibility of error through adsorption of phosphate on the filter.

Rate of Fixation:

It will be noted that the procedure developed for comparing the fixing power of soils involved the agitation of the soil and phosphate solution for a period of 24 hours. It should not be inferred from this statement, however, that fixation is complete at the end of that time. The period required for the attainment of a true equilibrium between a soil and soluble phosphate which has been added to it will depend upon the nature of the soil, the magnitude of the application, and the manner in which the resulting fixation is brought about.

A study was therefore made of the rate at which fixation occurs under the conditions of the experiment. For this work three soils of widely differing chemical properties were chosen: (a) a Waipio Substation soil; (b) a specimen from upland windward Kauai; and (c) a sample from the Hilo Coast region of Hawaii. From 10 - 12 extractions were made in the case of each of these soils, the period thereof varying from 5 minutes to 48 hours. A soil-solution ratio of 1 to 10 was used, soil and phosphate solution being employed in amounts of 50 grams and 500 milligrams, respectively. This corresponds to a treatment of 25,000 pounds P_2O_5 per acre-foot of soil*. While it may appear unreasonable to treat soils with phosphate in such large amount, even in the laboratory, it becomes necessary for the satisfactory study of our highest-fixing soils. This point is clearly illustrated in Table I, and, graphically, in Fig. 1.

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* This figure is based upon the value of 2,500,000 pounds air-dry soil per acre-foot.

TABLE I

RATES OF PHOSPHATE FIXATION BY HAWAIIAN SOILS

Time	Soil 9103 Waipio Substation mg P_2O_5 In soln.	Fixed	Soil 9077 Upland Windward Kauai mg P_2O_5 In soln.	Fixed	Soil 8922 Hilo Coast mg P_2O_5 In soln.	Fixed
0	500	0	500	0	500	0
5 min.	388	112	338	162	168	332
15 "	377	123	304	196	95	405
30 "	369	131	282	218	53	447
1 hr.	360	140	258	242	35	465
2 "	353	147	238	262	23	477
5 "	340	160	210	290	...	...
5.5 "	...	...	208	292	8	492
12 "	332	168	192	308	5	495
20 "	324	176	172	328	4	496
24 "	...	...	169	331	3	497
32 "	318	182	157	343	2	498
48 "	310	190	142	358	1	499

Referring to the chart, we observe that fixation proceeds at a tremendous rate during the first hour, the Hilo Coast soil absorbing 93 per cent of the added phosphate during that brief period. After the first hour the rate gradually drops off, becoming practically constant after 12 hours and remaining thus for the remainder of the period during which observations were made. Recent investigation by Davis, cited by Hance (2), of a high-fixing Manoa Valley soil indicates that equilibrium is not reached even after several weeks of continuous agitation of the soil-phosphate solution mixture. It thus becomes obvious that in a study of the fixing capacities of a relatively large number of soils the attainment of a true equilibrium is exceedingly impractical. Neither is it essential, for at the end of 24 hours, the data show fixation in the case of all three soils was proceeding at a very slow and constant rate. After due consideration of the factors involved, this period of extraction (24 hours) was chosen for the comparative study. Subsequent experiments have shown that results obtained upon this basis are wholly reproducible.

The fine state of subdivision of the soil, together with the constant mechanical agitation of the soil-phosphate solution mixture, offer conditions especially conducive to the rapid fixation of the phosphate. While it is desirable for the purposes of this study that such should be the case, the rates thus determined may not be taken as absolute measures of fixation under field conditions.

The writer has attempted to determine the rate at which fixation occurs when soluble phosphate is intimately mixed with a moist soil and allowed to stand. Fixation under such conditions more nearly approximates the process as it occurs in the field than is the case where the soil is constantly agitated with a large volume of phosphate solution. Such studies have not, however, been as successful as might be desired, for, in order to finally separate, for determination, the unfixed phosphate from the treated soil, it is necessary either to extract or dialyse the mixture. And in so doing it is impossible to be certain that one has effected a separation of

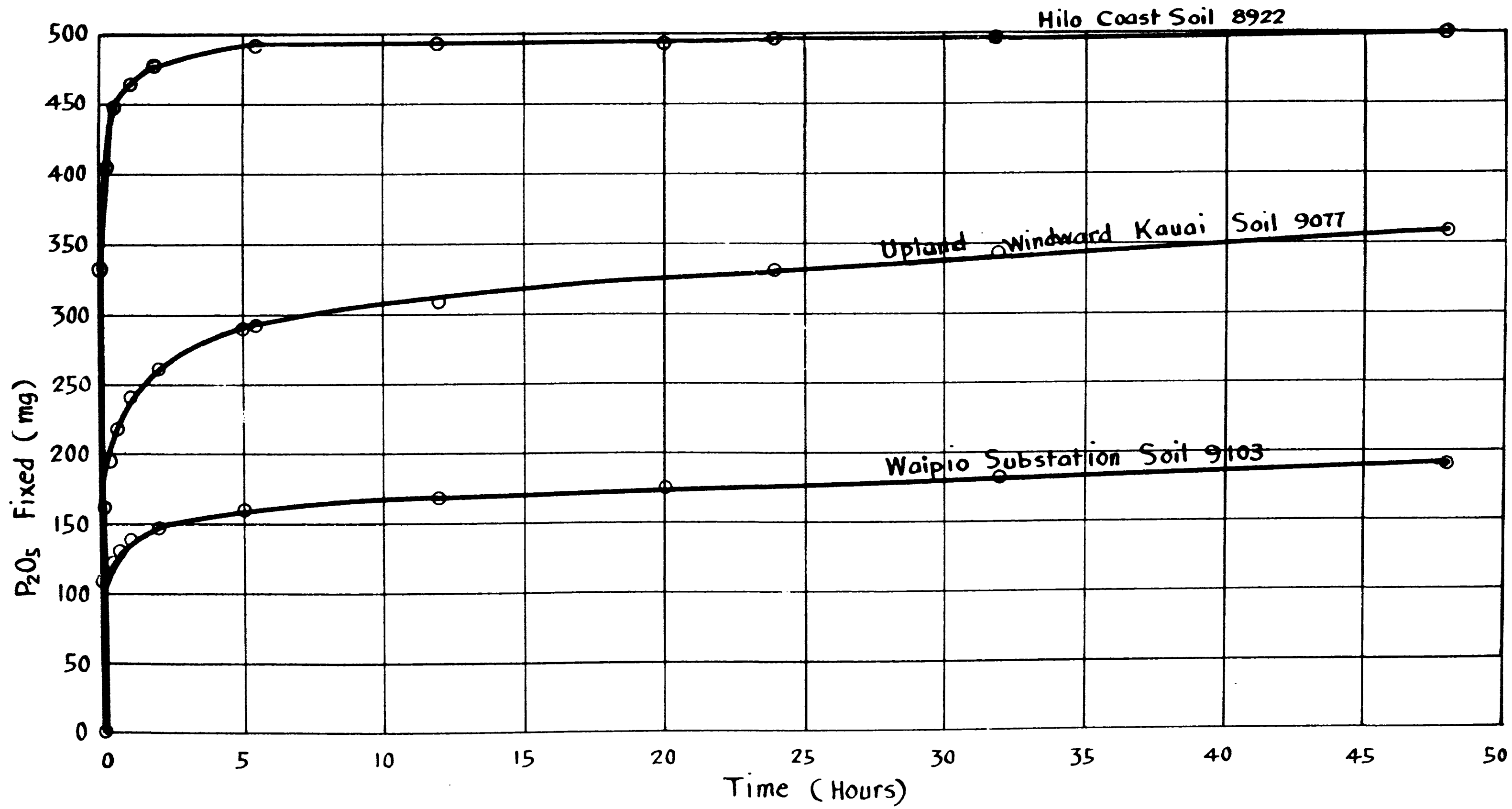

Fig. 1. Rates of phosphate fixation by typical Hawaiian soils. Ratio of soil to solution=1:10. P_2O_5 initially present in solutions=500 mg.

the unfixed from the fixed phosphate without either increasing or reversing the fixation.

Our laboratory studies suggest that the rate at which a given amount of soluble phosphate will become fixed under field conditions will depend upon the quantity of soil with which the phosphate is brought into intimate contact. Thus, for example, if one pound of phosphate is mixed with one thousand pounds of a moist soil, fixation will proceed at a more rapid rate than would be the case were the same quantity of phosphate mixed with but one hundred pounds of the soil. Experimentally, it was found that when a soil was treated with phosphate under the laboratory conditions already described, and at the rate of 2,500 pounds P_2O_5 per acre-foot, all of the added phosphate had become fixed within a period of four hours. When, however, an equal quantity of the soil was treated with ten times this amount of phosphate, or at the rate of 25,000 pounds per acre-foot, all other conditions being identical, fixation at the end of four hours amounted to but 70 per cent of the total. Reasoning by analogy we see that were 2,500 pounds of phosphate applied to one-tenth the amount of soil and solution employed in the first instance, fixation at the end of the 4-hour period, instead of being complete, would have amounted to but 70 per cent. The data further showed that before many more hours had elapsed, in the case of the larger treatment, the rate of fixation had greatly diminished, with indications that weeks or months would be required to complete the process. Now, when soluble phosphate is concentrated in the soil as, for instance, when it is applied in the line ahead of planting instead of being intimately mixed with the surface foot of soil it is brought into contact with but a minute fraction thereof. In such a case, assuming fertilization at the rate of 250 pounds P_2O_5 per acre, the relative quantities of phosphate and soil *in the zone of contact* would correspond not to this treatment, but to one of many thousands of pounds of P_2O_5 per acre-foot. Thus it is apparent that the result of restricting the zone of phosphate application is to effectively retard fixation. It follows that the *rate at which phosphate will undergo fixation in the field will be governed in large part by the manner in which it is applied.*

Treatment:

The value of a method which measures the properties of a soil depends upon the conditions of the test being identical in all cases. For example, devices such as the citric acid method of soil nutrient evaluation, tests for soil acidity and field experiments yield results which, though purely relative, nevertheless provide a basis for soil comparison and classification. So also, in preparing to determine their fixing power it became necessary to settle upon a definite phosphate treatment which would be applicable to all soils of the Islands. Following much preliminary experimentation a standard treatment was chosen consisting of 500 milligrams phosphoric acid (P_2O_5) as diammonium phosphate per 50 grams air-dry soil, which is the approximate equivalent of 25,000 pounds P_2O_5 per acre-foot. The selection of this very large standard treatment was based upon two observations: (a) that lesser quantities of phosphate are almost completely absorbed by our highest fixing soils, thereby defeating the purpose of the test; and (b) that more satisfactory differentiation between soils results from the use of large amounts of phos-

phate. These facts are clearly evidenced in Fig. 2, where are shown the results obtained by treating a group of higher fixing soils with amounts of phosphate ranging from 2,500 pounds to 25,000 pounds P_2O_5 per acre-foot.

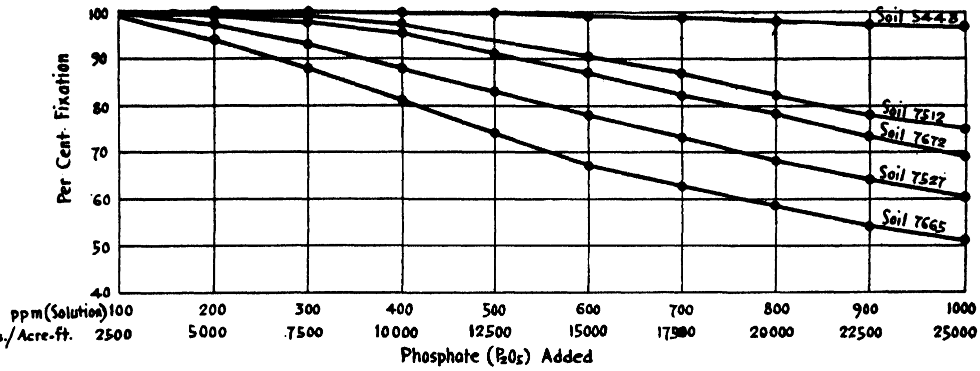

Fig. 2. Showing the differentiation obtained in the study of the fixing power of soils by the use of high phosphate treatments. Ratio of soil to solution=1:10. (Period of extraction=6 hours.)

All of these soils fixed between 98.8 and 100 per cent of the minimum application. On this basis it would be necessary to conclude that the fixing powers of these soils are identical. That such is clearly not the case is brought out by treatment with larger amounts of phosphate. When the application was increased to ten times the minimum, or 25,000 pounds, these same soils showed pronounced differences in fixing power. As treatment was increased, the highest fixing group of soils (represented by No. 5448 in the figure) continued to absorb practically all of the added phosphate. In contrast the percentage fixed by the other soils variously dropped off with each succeeding increment of P_2O_5 until at the maximum some indicated little more than 50 per cent fixation. Thus, by the use of this high treatment we have magnified our scale to the point where may be clearly distinguished differences in fixing power which do not appear following treatment with moderate quantities of phosphate.

It was felt that the purpose of the investigation would be better served and the objective more readily reached if, instead of attempting the tremendous task of evaluating the phosphate-fixing capacity of Hawaiian soils in general, our efforts were devoted to a comparatively detailed study of the soils of a few representative localities. The group finally selected comprised principally soils from the island of Kauai and the Hilo Coast region of Hawaii. The collection was amplified by a few specimens from Oahu and Maui. Previous tests by the fixation field kit, described by Hance (2), and experiences of agriculturists led us to believe that the material thus selected rather generally covered the range from the very high fixing soils to the class in which this property is not a problem. Specimens of soils originating in large part from coral formations are not included in the present investigation.

The comparative fixing powers of these soils, as measured by the method described in preceding pages, are given in Table II. The data are recorded in three forms: (a) as the concentration of P_2O_5 remaining in the solution at the end

of the period allowed for fixation, (b) as the number of pounds of P_2O_5 fixed by the soil, and (c) as the per cent of the added phosphate fixed. The soils listed in the table are, without exception, surface soils, and the order in which they there appear corresponds to their fixing power relative to the group as a whole.

TABLE II

CLASSIFICATION OF SOILS ACCORDING TO THEIR PHOSPHATE FIXING POWER

(Treatment=25,000 Lbs. P_2O_5/Acre-foot)*

Soil	Description of Soils	Final conc. P_2O_5 in soln. (ppm)	P_2O_5 Fixed Pounds	P_2O_5 Fixed Per cent
9103	Waipio Substation—Lowland	650	8,750	35.0
9104	Waipio Substation—Lowland	613	9,675	38.7
8233	West Maui—Lowland	558	11,050	44.2
8940	Leeward Kauai—Lowland	540	11,500	46.0
8938	Leeward Kauai—Lowland	523	11,925	47.7
8975	Leeward Kauai—Lowland	520	12,000	48.0
8977	Leeward Kauai—Lowland	515	12,125	48.5
8980	Leeward Kauai—Lowland	500	12,500	50.0
9201	Experiment Station Field—Lowland	485	12,875	51.5
8931	Central Kauai—Lowland	460	13,500	54.0
9200	Experiment Station Field—Lowland	455	13,625	54.5
8959	Windward Kauai—Lowland	438	14,050	56.2
9121	Central Maui—Lowland	433	14,175	56.7
8961	Windward Kauai—Lowland	428	14,300	57.2
8932	Central Kauai—Lowland	425	14,375	57.5
8979	Leeward Kauai—Lowland	420	14,500	58.0
8948	Central Kauai—Lowland	418	14,550	58.2
8968	Windward Kauai—Lowland	415	14,625	58.5
8976	Leeward Kauai—Lowland	408	14,800	59.2
8946	Central Kauai—Lowland	405	14,875	59.5
8930	Central Kauai—Lowland	403	14,925	59.7
8966	Windward Kauai—Lowland	398	15,050	60.2
8945	Central Kauai—Lowland	393	15,175	60.7
8983	Leeward Kauai—Lowland	390	15,250	61.0
8981	Leeward Kauai—Middle	375	15,625	62.5
8929	Central Kauai—Lowland	375	15,625	62.5
8970	Windward Kauai—Upland	353	16,175	64.7
9110	Windward Kauai—Upland	347	16,325	65.3
9077	Windward Kauai—Upland	337	16,575	66.3
8978	Leeward Kauai—Middle	335	16,625	66.5
8950	Central Kauai—Upland	323	16,925	67.7
8952	Central Kauai—Upland	320	17,000	68.0
8949	Central Kauai—Upland	305	17,375	69.5
9111	Windward Kauai—Upland	297	17,575	70.3
8969	Windward Kauai—Middle	270	18,250	73.0
8962	Windward Kauai—Lowland	263	18,425	73.7
8971	Windward Kauai—Upland	255	18,625	74.5
8934	Central Kauai—Upland	242	18,950	75.8
8944	Central Kauai—Upland	240	19,000	76.0
8965	Windward Kauai—Upland	230	19,250	77.0

* Based upon estimate of 2,500,000 pounds air-dry soil per acre-foot.

8936	Central Kauai—Upland	215	19,625	78.5
8943	Central Kauai—Upland	213	19,675	78.7
8955	Central Kauai—Upland	209	19,775	79.1
8933	Central Kauai—Upland	188	20,300	81.2
8942	Central Kauai—Upland	185	20,375	81.5
8953	Central Kauai—Upland	185	20,375	81.5
8956	Windward Kauai—Upland	185	20,375	81.5
8941	Leeward Kauai—Upland	89	22,775	91.1
7669	Leeward Kauai—Middle	75	23,125	92.5
8958	Windward Kauai—Upland	68	23,300	93.2
8986	Leeward Kauai—Upland	56	23,600	94.4
8861	Hilo Coast—Lowland	38	24,050	96.2
7852	Manoa Substation, Oahu	34	24,150	96.6
8916	Hilo Coast—Lowland	20	24,500	98.0
8915	Hilo Coast—Lowland	19	24,525	98.1
8918	Hilo Coast—Lowland	18	24,550	98.2
8914	Hilo Coast—Lowland	17	24,575	98.3
8917	Hilo Coast—Lowland	17	24,575	98.3
8879	Hilo Coast—Middle	14	24,650	98.6
8893	Hilo Coast—Lowland	14	24,650	98.6
8913	Hilo Coast—Lowland	13	24,675	98.7
8868	Hilo Coast—Middle	11	24,725	98.9
8867	Hilo Coast—Middle	10	24,750	99.0
8919	Hilo Coast—Lowland	10	24,750	99.0
8924	Hilo Coast—Upland	10	24,750	99.0
8858	Hilo Coast—Lowland	9	24,775	99.1
8921	Hilo Coast—Upland	9	24,775	99.1
8920	Hilo Coast—Upland	8	24,800	99.2
8871	Hilo Coast—Upland	8	24,800	99.2
8889	Hilo Coast—Upland	8	24,800	99.2
8887	Hilo Coast—Lowland	7	24,825	99.3
8922	Hilo Coast—Upland	6	24,850	99.4
8925	Hilo Coast—Upland	6	24,850	99.4
8898	Hilo Coast—Lowland	5	24,875	99.5
8882	Hilo Coast—Lowland	4	24,900	99.6

Note: "Central Kauai" refers to the approximate center of the sugar-producing belt of that island.

CLASSIFICATION

Reference to Table II shows that of the seventy-five soils examined, specimens from the Waipio Substation possess the least tendency to fix phosphates, absorbing only slightly in excess of one-third of the amount applied. Next in order is a lowland Maui soil, followed by a group of very productive soils from the dry, leeward side of Kauai. Indicating slightly greater fixation are the Experiment Station fields and certain of the strictly lowland areas of central and windward Kauai. These soils, plus those of lower elevation on Kauai generally, cover the range of fixation from the minimum to 65 per cent. At the latter value are first encountered the upland soils of Kauai. These almost exclusively fill the gap from 65 to where is found at 96 per cent the lowest fixing soils of the Hilo Coast group. Comparable in fixing power with soils of the latter type is the infertile Manoa Substation soil. The greatest fixing power was found in the soils of the Hilo Coast, all specimens from this region fixing above 96 per cent of the added phosphate.

A group of four unusually high fixing Kauai soils (c.f., fixation values 91.1-94.4 per cent in Table II) constitute a noteworthy departure, with respect to this property, from the other soils of that Island. Of these four specimens, two were obtained from abandoned, extreme upland cane fields. One was taken from, and is typical of, the barren soil found on the Kokee road well above the uppermost fields of the Kekaha Sugar Co., Ltd. The fourth represents a growth failure area (middle belt) on the leeward side of the Island.

It is very probable that an extended survey of Hawaiian soils would result in the finding of specimens lower in fixing power than any examined in the course of this study. At the same time there is excellent reason for believing that all of our soils are capable of fixing this nutrient in relatively large amounts.

Fixing Power of Subsoils:

The surface soils of the upland areas of the Kauai rain belt region are in large measure very shallow, being in some instances but a few inches in depth. The point of application of phosphates in soils which fix this nutrient is of very practical importance. The placement of phosphatic fertilizer relative to the subsoil would become of obvious importance were investigation to reveal marked differences in the fixing power of surface and subsoils. Believing that such information should be obtained, a study was made of the subject, employing the technic already described. The resulting data have been augmented by a supplementary investigation of fixation at lower phosphate-to-soil ratios. A comparison of the fixing powers of surface and corresponding subsoils is given in Table III.

TABLE III

FIXATION BY SURFACE SOILS AND SUBSOILS COMPARED
ISLAND OF KAUAI

Soil	Description of Soil	Lbs. P_2O_5 Remaining Unfixed Following Treatment at Rate of: 2,500 Lbs./Acre	7,500 Lbs./Acre	*Index Per Cent Fixation
8959	Windward Kauai—Lowland, surface..	25.0	....	56.2
8960	Windward Kauai—Lowland, subsoil..	5.0	....	72.5
8948	Central Kauai—Lowland, surface....	30.0	....	58.2
8947	Central Kauai—Lowland, subsoil.....	2.5	....	67.7
8930	Central Kauai—Lowland, surface.....	....	475	59.7
8928	Central Kauai—Lowland, subsoil.....	....	30	70.8
8966	Windward Kauai—Lowland, surface..	....	525	60.2
8967	Windward Kauai—Lowland, subsoil..	....	15	77.5
8981	Leeward Kauai—Middle, surface.....	15.0	....	62.5
8982	Leeward Kauai—Middle, subsoil.....	5.0	....	69.7
8970	Windward Kauai—Upland, surface...	....	425	64.7
8973	Windward Kauai—Upland, subsoil...	....	10	84.1
8950	Central Kauai—Middle, surface......	5.0	....	67.7
8951	Central Kauai—Middle, subsoil......	2.5	....	73.3

* Values in this column represent fixation under "standard conditions."

8962	Windward Kauai—Lowland, surface..	....	125	73.7
8963	Windward Kauai—Lowland, subsoil..	....	13	84.0
8971	Windward Kauai—Upland, surface...	....	125	74.5
8972	Windward Kauai—Upland, subsoil...	....	8	90.7
8965	Windward Kauai—Upland, surface...	....	100	77.0
8964	Windward Kauai—Upland, subsoil...	....	8	92.8
8936	Central Kauai—Upland, surface......	....	75	78.5
8937	Central Kauai—Upland, subsoil......	....	20	91.0
8955	Central Kauai—Upland, surface......	2.5	....	79.1
8954	Central Kauai—Upland, subsoil......	0	....	95.6
8956	Windward Kauai—Upland, surface...	5.0	....	81.5
8957	Windward Kauai—Upland, subsoil...	2.5	....	89.9

The figures in the third column of the table, indicating "per cent fixation" are those derived from treatment with the standard amount of phosphate, i. e., 25,000 pounds P_2O_5 per acre-foot of soil. In the first and second columns are shown, in pounds, the quantities of phosphate remaining unfixed subsequent to treatments of 2,500 and 7,500 pounds P_2O_5, respectively. Examination of the data in the first column shows that in the case of every pair of soils thus studied the ability of the subsoil to absorb phosphates far exceeded that of the surface soil. This fact becomes strikingly evident when we examine the results obtained through treatment at the rate of 7,500 pounds P_2O_5. Under these conditions the phosphate remaining unfixed in the case of surface soils amounts to from four to forty times the quantity unfixed by corresponding subsoils. Carrying the results of our laboratory work to the field we conclude that phosphate applied within the surface soil will be far more available than if placed in the higher fixing subsoil. Whether or not, in a specific case, it will be practical to place the phosphate entirely within the surface soil will depend in large part upon the relative proportions of the nutrient-absorbing roots in the two horizons.

Total Fixing Capacity of a Soil:

The query is frequently made: "How much phosphate would it require to completely overcome the capacity of a soil to fix phosphates?" The answer to this question is implied by the following observations: A low fixing soil (c.f., 8233 in Table II) was treated with ammonium phosphate in amounts ranging up to 125,000 pounds P_2O_5 per acre-foot. Of the maximum treatment, 17 per cent was fixed under the conditions of the experiment. Above 10,000 pounds P_2O_5, this soil absorbed a definite proportion (approximately 7 per cent) of each added increment of phosphate until the above stated maximum had been reached. Hence, although the proportion of the total added phosphate fixed decreased as the treatment was increased, nevertheless, the total quantity absorbed became greater with increased application. The quantity of phosphate required to completely overcome the ability of a colloidal soil to fix this material appears then to be indeterminate, total fixation increasing as the concentration of P_2O_5 in the contacting solution is increased, probably up to the limits of solubility of the phosphate.

While the subject is of importance theoretically, indicating something as to the nature of fixation, it is without practical application. The fundamental question with which the agriculturist is concerned becomes, *"What is the minimum amount of phosphate necessary to add to a particular soil in order to establish and maintain in the soil solution a concentration of phosphate sufficient to meet the needs of the current crop?"* It thus becomes apparent that we are not from a practical standpoint concerned with the total fixing capacities of soils. Rather we are interested in determining that portion of a standard phosphate treatment which remains unfixed, or being fixed, is yet able to rapidly reenter the soil solution as the nutrient is withdrawn from that medium either by the cane roots or by leaching. It will be of interest to compare a "high"- and a "low"-fixing soil on the basis of the phosphate remaining unfixed subsequent to treatments of various magnitudes. This comparison is accomplished in Table IV and, graphically, in Fig. 3.

TABLE IV

COMPARISON OF AMOUNTS OF P_2O_5 REMAINING UNFIXED FOLLOWING EXTRACTION OF PHOSPHATE SOLUTIONS OF VARIOUS CONCENTRATIONS BY A "HIGH" AND BY A "LOW" FIXING HAWAIIAN SOIL

100 p.p.m. $\Leftrightarrow$ 2,500 Lbs./Acre-foot (Period of Extraction=6 Hrs.)

Initial conc. P_2O_5 (p.p.m.)	Final conc. P_2O_5 (p.p.m.) Soil 8233	Final conc. P_2O_5 (p.p.m.) Soil 5448
0	< .1	0.0
100	5.	0.0
200	32.	0.0
300	83.	0.3
400	148.	1.5
500	225.	4.0
600	298.	7.0
700	....	10.
800	455.	16.
900	535.	22.
1000	608.	31.

Note: Figures refer to concentrations of P_2O_5 in the solutions. Ratio soil to phosphate solution=1:10.

Referring to the table we note in the case of the high fixing soil (5448) that applications of phosphate as large as 400 p. p. m. (equivalent to 10,000 pounds per acre) have resulted in but 1.5 p.p.m. of phosphate remaining in solution. In contrast, the low fixing soil absorbed slightly less than two-thirds of an equivalent treatment, the quantity of phosphate thus remaining unfixed being equal to 3,700 pounds. Reference to the figure shows that an application of 2,500 pounds of P_2O_5 to the one soil results in more phosphate remaining unfixed than does five times that quantity, or 12,500 pounds, to the other.

Correlations With Field Observations

In order that a measure of the fixing power of a soil be of practical value to the plantation it is essential that the chemical data be interpretable in terms of crop

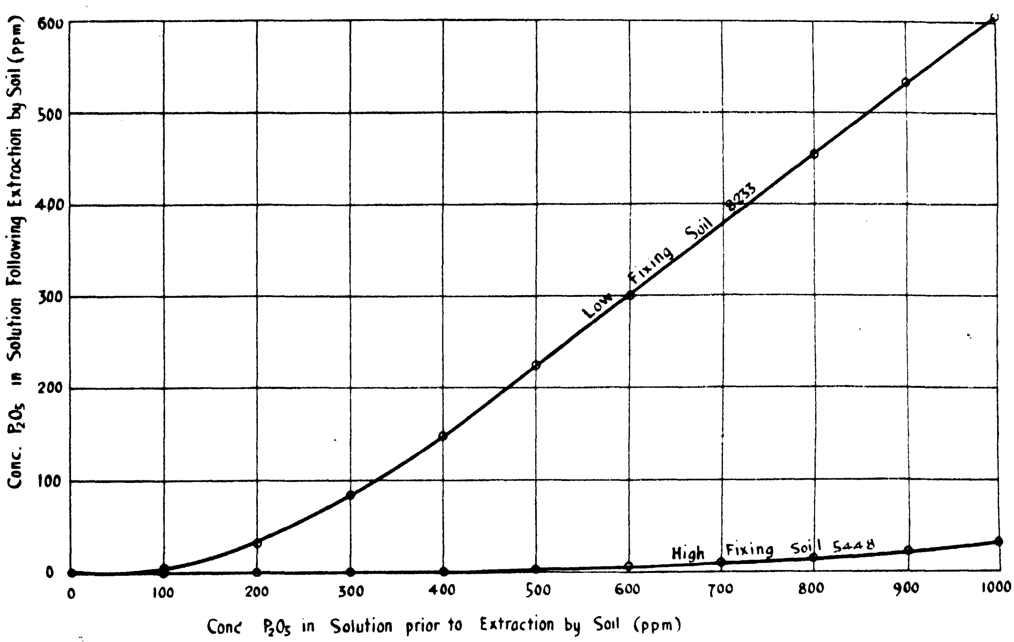

Fig. 3. Showing the quantities of phosphate remaining unfixed by a "high" and a "low" fixing soil following treatment with various amounts of phosphate. One hundred p.p.m. is the equivalent of 2500 pounds P_2O_5 per acre-foot of soil. (Period of extraction= 6 hours.)

response to phosphate fertilization. While field observations are lacking relative to many of the soils included in this study it will be seen, from the following correlation, that the degree to which these soils absorb phosphates, as shown by chemical test, may generally be taken as being roughly indicative of the availability to the crop of soluble phosphates applied thereon.

Reference to Table II shows the soils of the Waipio Substation to be the lowest in fixing power of any encountered in this study. A well-conducted fertilizer experiment harvested in this area in 1933 gave no indication that the added phosphate was not entirely available for utilization by the crop. Manifesting slightly greater absorption than these soils is a specimen from the island of Maui which has been extensively studied both in the laboratory and in the field. This phosphate-deficient soil has been conclusively shown to possess little, if any, ability to withhold added phosphate from the crop. Next in order, and covering a rather wide fixation range, are the soils of lower elevation on the island of Kauai. Upon a few of the higher fixing soils of this group it has been found profitable to employ soluble phosphates in excess of amounts assimilable by the crop. Generally speaking, however, there appears little reason to believe that soluble phosphates applied to these soils are not in large part available to the current cane crop. Table II shows the upland soils of Kauai to be capable of greater phosphate absorption than the lowland soils. Correspondingly, economic response to the higher treatments on the soils of that Island is most pronounced and most frequently met with in the regions of higher elevations. Isolated, with respect to their fixing power, from other Kauai soils are four infertile areas of high fixation. On only one of these have fertilizer tests been conducted. In this instance response was obtained to applications of soluble phos-

phates only when these exceeded 1,000 pounds P_2O_5 per acre. Soils of the Manoa Substation, according to our classification, exhibit fixing power comparable in extent to that of the less extreme Hilo Coast soils. Cane growing on these high-fixing Substation soils does not respond to fertilization with phosphate except in amounts equal to many times the requirements of the current crop. All of the Hilo Coast soils examined fixed above 96 per cent of the applied phosphate. This fact, viewed in the light of the foregoing discussion, might well lead us to expect, if we did not know otherwise, that normal cane crops could not be produced on the soils of the Hilo Coast region except through the use of great quantities of phosphate. Such, we know, is not the case. Manifestly then, there exists a fundamental difference between the soils of this region and the other widely selected specimens examined in the course of this study.

Conclusions

It is very probable that most, if not all, Hawaiian soils are capable of fixing upwards of several thousand pounds P_2O_5 per acre-foot under the laboratory conditions outlined in this paper. Nevertheless, we find the property of fixation to be far more pronounced in certain of our soils than in others, as is shown, for example, by a comparison of lowland Kauai with Hilo Coast soils. However, up to the point at which fixation begins to interfere with the absorption of phosphate by the plant roots, this property of the soil, far from being an objectionable characteristic, may be of decided benefit in holding the added phosphate against leaching action. Soils of the Waipio Substation appear to approximate this hypothetical group. Thus, while specimens from this district were found, by laboratory test, to possess considerable capacity to absorb phosphates, yet moderate quantities of the nutrient added to and doubtless fixed by this soil have been shown to be largely, if not wholly, available to the current cane crop. Beyond this point, however, fixation may present a problem. With the exception of the Hilo Coast soils the degree to which fixation occurs is roughly indicative of the availability to the crop of soluble phosphates applied in the field.

Our laboratory studies have shown that the smaller the quantity of soil with which a given amount of phosphate comes into contact the greater will be the period during which a part thereof will remain unfixed. We may conclude therefrom that concentrating soluble phosphatic fertilizer in the soil will result in less rapid fixation than would be the case were it more generally distributed. The success of such a scheme to combat fixation will depend largely upon the absorbing capacity of the relatively small number of roots penetrating this very limited zone of comparatively high phosphate concentration.

Where subsoils are higher in fixing power than corresponding surface soils, and where soluble phosphates are used, it is important to direct attention toward applying the phosphatic fertilizer in the lower fixing surface soil. The degree to which such a practice will prove beneficial will depend largely upon the depth of the surface soil and the proportion of the active roots contained therein.

Summary

(a) The development in this laboratory of a method for comparing the fixing capacities of soils is discussed in detail.

(b) Seventy-five surface soils, principally from the island of Kauai and the

Hilo Coast region of Hawaii, are classified according to their phosphate-fixing power.

(c) Of the soils thus far investigated, those possessing the least capacity to absorb phosphates were found at the Waipio Substation. Extreme fixation was shown to occur in the soils of the Hilo Coast.

(d) Lowland soils of the island of Kauai were shown to be lower in phosphate-fixing power than upland soils.

(e) The lowest fixing soils of the Kauai soils studied were found at the lower elevations on the dry, leeward side of the island.

(f) The extent to which fixation occurs was shown, in general, to characterize the soils of a given locality.

(g) Fixation was shown to be more severe in the subsoils of Kauai than in the corresponding surface soils.

(h) All the soils studied fixed upwards of several thousand pounds P_2O_5 per acre-foot under the conditions of the test.

(i) The rates of fixation by typical Hawaiian soil types were studied. When soils were treated with solutions of phosphate and subjected to continuous mechanical agitation, fixation was found to occur at a tremendous rate during the first hour. Subsequently it diminished, becoming very low and constant in about 12 hours and continuing thus for the balance of the 48-hour period during which the test was conducted.

(j) The higher fixing soils were found to absorb phosphates more rapidly than the lower fixing soils.

(k) The rate at which fixation occurs was found to depend upon the relative quantities of soil and phosphate reacting. This suggests that fixation under field conditions may be effectively retarded by applying the phosphate in limited zones accessible to the cane roots.

(l) Excepting the soils of the Hilo Coast, a general correlation was found to exist between the degree to which fixation occurs in soils and the availability therein of applied soluble phosphate.

The writer wishes to acknowledge the helpful suggestions, constructive criticisms and assistance in interpretation of data received from his associates—Dr. Hance, Mr. Borden and Mr. Davis. He also gratefully acknowledges the generous aid received in securing the material necessary for this work by members of plantation staffs, especially J. N. P. Webster, and by members of the Agricultural Department of this Experiment Station.

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Applying Mill By-products to Cane Fields—Costs and Comments*

By R. BRYAN, J. C. CARTER and M. J. BLACK

From a questionnaire sent to all plantations on Hawaii for data concerned with costs in connection with hauling and handling press cake, molasses, and mill ash in the fields, we have compiled the following information:

PRESS CAKE

Hauling Cost:

Ten plantations report average hauling distances from 1½ to 6 miles; the average for the ten plantations being about 3½ miles.

Nine plantations report hauling press cake by trucks at a cost ranging from $0.035 to $0.52 per ton mile; the average being about $0.22 per ton mile.

Three plantations report hauling press cake by railroad at a cost ranging from $0.03 to $0.09 per ton mile.

Four plantations report hauling press cake by pack animals at a cost ranging from $0.12 to $0.63 per ton mile.

One plantation reports hauling press cake by hoists at a cost of $0.20 per ton mile.

Cost of Applying and Amounts Applied:

One plantation reports a cost of $0.47 per ton for applying 21.5 tons per acre, using sleds.

Two plantations report using irrigation water as a means of applying press cake; the cost at one being $0.10 per ton for a 20-ton application, and at the other $0.15 per ton for an 11-ton application.

Four plantations report using pack animals for distributing press cake in the fields, $0.40 per ton for a 20-ton-per-acre application, $0.12 per ton for a 10-ton application, $1.25 per ton for a 17-ton application, and $0.10 per ton for a 40-ton application.

For costs on bagging and applying we find six plantations reporting costs ranging from $0.05 to $1.00 per ton, with the tons applied per acre ranging from 10 to 40 tons.

Two plantations report fluming press cake on unirrigated lands; $0.06 per ton to apply 18 tons per acre, and $0.27 per ton to apply 30 tons per acre are their respective costs.

In answer to "Have you at any time observed a residual effect from applications of press cake?" we have three plantations answering "No," five answering "Yes," one "Occasionally," and one "No observations." Two of the plantations answering "Yes" state the effect lasts for three crops.

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* A report of a committee selected to study this question and presented at the 1934 group meeting of field men and others on the Island of Hawaii.

In answer to the question, "Is the amount of commercial fertilizer reduced on areas where press cake has been applied?" we find nine plantations answering "No," two "Yes," and one "Occasionally." Five of the plantations answering "No" state that the press cake is applied on poor areas only.

We would like to quote some of the remarks taken from the questionnaires:

Paauhau Sugar Plantation Company: We believe that measurable results from applications of press cake cannot be readily obtained.

Onomea Sugar Company: Plant cane without press cake in the furrows is slower in starting. Mud press gives the young roots plant food immediately.

Olaa Sugar Company: Before the installation of the Oliver filters and when using the old presses, the sucrose in the mud ran about 3 per cent. Our recovery with the Oliver filters is about .3 per cent and it was noted that the same results were not being obtained in the fields from applications of mud press. By adding molasses at the rate of approximately one to three, the sucrose content has been brought back to more than it was before and a good response is again evidenced in the field.

Laupahoehoe Sugar Company: We have found mud press to be beneficial; particularly in improving the fertility of poor spots in the fields.

Waiakea Mill Company: Heavy applications of mud press causes a deleterious effect on the juice.

Hakalau Plantation Company: In our fields in particular, the cane tonnage dropped when we reduced the fertilizer application on areas which had received press cake.

Hutchinson Sugar Plantation Company: We generally apply press cake on the knolls and poor spots in the fields.

Honomu Sugar Company: Press cake appears to be particularly beneficial to the middle belt fields.

The Honomu Sugar Company submits the following interesting cost figures on applying a mixture of press cake and molasses. The mixture is hauled by trucks to the fields, sledded to various parts of the fields and spread by hand, with the exception of Field 36B, which was flumed:

TOTAL MUD-PRESS CAKE MIXED WITH 18 PER CENT MOLASSES MADE AND DELIVERED TO FIELDS FROM JANUARY, 1933, TO SEPTEMBER, 1933

Field No.	Tons Press Cake	Tons Molasses	Total Tons	Total Cost	Cost per Ton	Acres Appl.	Cost per Acre	Haul Distance, Miles
4........	117.42	25.78	143.20	$ 146.49	$1.023	15	$ 9.77	3
6-A......	512.42	112.48	624.90	566.35	.906	55	10.30	3
23-A.....	223.04	48.96	272.00	162.17	.596	25	6.49	2½
25-A.....	160.15	35.15	195.30	125.29	.641	18	6.96	3
25-B.....	291.92	64.08	356.00	329.90	.927	40	8.25	3
32.......	40.67	8.93	49.60	44.83	.904	5	8.97	1
37.......	285.61	62.69	348.30	301.62	.866	32	9.43	3
Total....	1631.23	358.07	1989.30	$1676.65	$ .842	190	$ 8.82	
Flumed 36-B...	271.17	59.53	330.70	239.13	.723	22	10.87	3½
Grand Total...	1902.40	417.60	2320.00	$1915.78	$ .826	212	$ 9.04	

This mixture contains by analysis:
0.56% N, 0.96% P_2O_5, 0.23% K_2O, 1.30% CaO.

The Onomea Sugar Company submits the following costs on applying press cake with a mechanical spreader hauled by tractor. The cake is hauled to the

fields in dump trucks, and a movable ramp facilitates dumping the loads directly into the spreader:

Onomea Sugar Company, Field 80, applied April, 1933:

Two dump trucks, labor (2 men and superintendence)	$5.16	
Tires per day	1.00	
Tax	.40	
Gasoline, oil and grease for 2 trucks per day	3.40	
Estimated repairs to trucks per day	1.50	$11.46
Tractor operator and superintendence	$1.58	
Mechanical spreader	1.08	
Gasoline, oil and grease for tractor per day	7.00	
Repairs to tractor per day	.75	10.41
Five men and superintendence loading bin		5.40
Total cost hauling and spreading		$27.27
Forty-four loads of mud press per day equal		77 tons
Seventy-seven tons of mud press, 10 tons per acre, cover		7.7 acres
Cost per ton mud press		$ .354
Cost per acre		$3.54
Distance mud press hauled—mill to field		1 mile

The Paauhau Sugar Plantation Company reports:

During 1928 we composted about 1833 tons of molasheake. By analysis this contained .7 per cent N, 1.1 per cent P_2O_5, .9 per cent K_2O, and 1.8 per cent CaO. Cost per ton for composting and spreading, without considering overhead on labor and repairs or depreciation on equipment was:

Composting	$1.16 per ton
Spreading	1.37 " "
Total	$2.53 " "

Molasses

Very little information is available on costs of transporting and applying molasses.

One plantation reports a cost of $0.27 per ton mile, hauling molasses by trucks. Two plantations report costs of $0.03 and $0.05 per ton mile hauling by railroad. One plantation reports a cost of $0.10 per ton mile hauling by hoists. One plantation reports an application cost of $0.10 per ton for a 5-ton application in irrigation water.

We are fortunate in being able to present costs on the applying of 306 tons of molasses recently at Hamakua Mill Company. The molasses was hauled by a "75" tractor in a large tank wagon of the crawler type equipped with a pipe spreader; all of the hauling was up steep grades. When we consider the amount of potash applied per acre, the costs do not appear prohibitive. This method of applying molasses to unirrigated areas is deserving of further attention.

Hamakua Mill Company, Field 12, Paauilo: A Diesel "75" was used for the hauling.

Average number of trips per day	2.13
Length of haul—one way, miles	1.50
Average tons of molasses per trip	6.25
Average tons molasses applied per acre	4.71
Per cent K_2O in Hamakua Mill Company molasses	3.24
Pounds K_2O applied per acre	305
Average cost of applying per acre	$ 2.13
Average cost of applying per ton	$ .45

These averages were drawn from the following figures: 306 tons of molasses applied to 65 acres over a total of 23 days. The equipment required a driver and helper.

Minimum Requirements for Bundle Weighing and Taring in Grade "A" Field Experiments*

By R. J. Borden, W. C. Jennings and H. L. Weber

Bundle Weights

Previous Studies:

A review of the data concerned with bundle weights was made with a view of securing a good idea of the variations that had been encountered, and the possible error that might be introduced into plot cane yields when only every third or fifth bundle was weighed.

(1) From a study in 1916 by W. P. Alexander on 13 plots at Pepeekeo Sugar Company, we note:

	Tons Difference: Every Bundle vs. Every Third Bundle	Per Cent Diff.	Tons Difference: Every Bundle vs. Every Fifth Bundle	Per Cent Diff.
Maximum error for plot	.39 ton	3.2	.90 ton	7.5
Minimum error for plot	.09 "	.9	.12 "	1.3
Average error for plot	.21 "	2.02	.31 "	2.99

Average bundle weight—53.7 lbs.
Average number of bundles per plot—386.
Every third bundle means that approximately 125 bundles were weighed.
Every fifth bundle means that approximately 75 bundles were weighed.

(2) From a study in 1919 by Y. Kutsunai from 24 "X" plots of Experiment 4 at Onomea Sugar Company:

	Tons Difference: Every Bundle vs. Every Third Bundle	Per Cent Diff.	Tons Difference: Every Bundle vs. Every Fifth Bundle	Per Cent Diff.
Maximum error for plot	.136 ton	3.5	.24 ton	5.3
Minimum error for plot	.006 "	.1	.008 "	.2
Average error for plot	.054 "	1.2	.07 "	1.7

Average bundle weight—54.5 lbs.
Average number of bundles per plot—171.
Every third bundle means that approximately 57 bundles were weighed.
Every fifth bundle means that approximately 34 bundles were weighed.

(3) From a study (about 1920) by T. E. Merriam—40 plots:

	Every Third Bundle	Every Fifth Bundle
Largest error	3.9 %	4.8 %
Smallest error	0	.1 "
Average error	1.06 "	1.72 "

* A report of a committee selected to study this question and to make recommendations concerning it to the 1934 group meeting of field men and others on the Island of Hawaii.

(4) From a study in 1922 by Y. Kutsunai at the Hilo Sugar Company:

No. of Bundles	Probable Maximum Error
5	6.6%
10	4.5 "
20	3.1 "
30	2.6 "
40	2.2 "
50	2.0 "
60	1.8 "

Mr. Kutsunai comments that "at least 30 bundles must be weighed to get an accuracy within 3 per cent."

(5) Studies made in 1929 by R. J. Borden from Honokaa and Hilo Sugar Company bundle weights showed that departures from the true average weight were seldom greater than 2 pounds per bundle when only every third bundle was weighed. This was equivalent to an error of approximately 2½ per cent. Every third bundle meant that from 33 to 55 bundles were weighed in these studies.

(6) L. S. McLane in 1931 studied bundle weights from 14 plots at Honomu Sugar Company and found that the greatest plot yield difference as calculated from every bundle and from every third bundle was only .8 per cent. He concluded that "every third bundle is sufficiently accurate in experimental plots at Honomu." Approximately 50 bundles per plot were weighed.

(7) In 1930, R. K. Conant studied a large number of bundle weights at Olaa Sugar Company and concluded that "yields obtained by weighing every third or every fifth bundle in plots of 1/20 acre, differed from yields obtained by weighing all bundles per plot sufficiently to contend that where large variation of weights between bundles exists, it is necessary to weigh all bundles to insure accuracy."

Recent Studies:

We have recently made three statistical studies of bundle weights with results as follows:

Source	No. of Bundles	Av. Wt. Lbs.	Standard Deviation Lbs.	Coefficient of Variation Per Cent	Approximate Theoretically Possible Deviation from Actual Bundle Weight for Average of 36 Bundles	49 Bundles
1. Olaa "Y" plots..	280	76	14.5	19.0	5 lbs.	4 lbs.
2. Hilo—1929	200	80	8.2	10.2	3 "	2½ "
3. Pepeekeo—1933...	940	87	8.0	9.2	3 "	2½ "

These wide differences in variation indicate the variable nature of individual cane bundle weights, and show how necessary it is for us to secure an average bundle weight from a considerable number of bundles if our plot yield is to be accurately determined from such data.

Bundle Tares

Much less tare data were available for study, but those available were subjected to a statistical study with results as follows:

Source	No. of Tares	Average Tare	Standard Deviation	Coefficient of Variation
Olaa	828	5.5 lbs.	3.1 lbs.	56.3%
Pepeekeo	2023	8.13 "	2.67 "	32.8 "
Honokaa No. 1...............	20	16.5 "	4.0 "	24.2 "
Honokaa No. 2...............	20	19.7 "	9.8 "	49.7 "
Onomea No. 8...............	12	5.2 "	1.7 "	32.7 "

Here likewise we note extreme variability in the weights of bundle tares.

The data furnished several years ago by Mr. Conant from Olaa Sugar Company, Experiment 30-2, offered interesting evidence of significant differences between the average tares for different treatments, as well as between different plots of the same treatment. Thus we feel that separate tares must be determined for each plot of each treatment.

We believe, however, that there is no point in securing a greater degree of accuracy in tare figures than that which we can secure in bundle weights, and vice versa. Thus we are now led to present two tables: one that gives the standard errors for the means of 10, 20, 30, 40, 50 and 100 bundle weights, set down opposite varying degrees of standard deviation, and another that gives a corresponding scale of standard errors for the means of 2, 3, 4, 5, 6, 8 and 10 tares as set opposite a range of standard deviation figures for tares.

TABLE 1. STANDARD ERRORS OF THE MEAN BUNDLE WEIGHT (Pounds)

Standard Deviation of a Single Bundle Weight	Bundles 10	20	30	40	50	100
6	1.90	1.34	1.10	.95	.85	.60
7	2.21	1.57	1.28	1.11	.99	.70
8	2.53	1.79	1.46	1.26	1.13	.80
9	2.85	2.01	1.64	1.42	1.27	.90
10	3.16	2.24	1.83	1.58	1.41	1.00
15	4.74	3.35	2.74	2.37	2.12	1.50

TABLE 2. STANDARD ERRORS OF THE MEAN TARE (Pounds)

Standard Deviation of a Single Tare	Tares 2	3	4	5	6	8	10
2	1.41	1.15	1.00	.89	.82	.71	.63
3	2.12	1.73	1.50	1.34	1.22	1.06	.95
4	2.83	2.31	2.00	1.79	1.63	1.41	1.26
5	3.54	2.89	2.50	2.24	2.04	1.77	1.58

From these two tables one may choose a number of tares that will give comparable accuracy with the number of bundle weights averaged, after he has estimated or determined the average variations (standard deviations) for his usual bundle and tare weights. For example: if we assume the standard deviation for bundle weights at 8 pounds and for tares at 3 pounds, we can obtain approximately the same degree of accuracy in both weights from weighing (a) 30 bundles (standard error 1.46 pounds) and from 4 tares (standard error 1.50 pounds); (b) with 40 bundle weights and 6 tares, etc.

Because these standard deviations are so differently affected by location, cutter, character of burn, variety, treatment, etc., it is difficult to justify a recommendation for any definite number of bundle weights and tares for Grade "A" experiments. Realizing, however, that it is desirable to set a definite minimum qualification, we would recommend that not less than 40 bundles be weighed per plot (unless the total number of bundles in the plot is less than 40, in which case all should be weighed), and not less than 6 tares per plot (2 tares per cutter) be taken, in order to secure the net cane yield from which the plot tons cane per acre will be calculated. These 40 bundles should be taken in such a way that they reliably represent all the cane grown on the plot.

"A Correction for the Juice Sampling Error That is Due to Water in Field Trash"*

By H. F. Hadfield

At the last meeting of this group, held during January, 1933, a report was read, based on the fact that whenever flumed cane was accompanied with large amounts of field trash over a cane carrier, especially if the carrier is of the steel slat type, the field trash absorbed, and also carried over with it, large quantities of flume water into the first expressed juice, thus reducing the density, and causing an "Error" which required correcting; otherwise the quality ratio, or the calculated tons of cane would be higher than it should be.

Your Committee has conducted several experiments with a view of finding some "Factor" in order to correct this error, with the following results: In reality the factor advocated by your committee is not an absolute juice factor, but nevertheless of infinite value, and may be used as such. The real absolute juice factor may be determined by means of a dry crushing test, which includes the juice extraction per cent cane, the Brix of each mill, as well as the purity of the last mill juice, and the pol of the last mill bagasse, which is not included in the factor advocated by your committee.

This official method of determining the absolute juice factor seems, however, to be too low, as the following tests show:

Dry crushing tests for absolute juice factor....	99.19
	100.06
	97.41
	100.40

To an observer watching the cane entering the crusher it is obvious that quantities of water are being carried over into the first expressed juice. The absolute juice factor should therefore be above 100. Subsequent tests prove this to be the case, and the above method does not seem to account for this error of water entering the first expressed juice.

Experiment 1

The first experiment was based upon a suggestion that the Brix of the juice from the bagasse roll of the first mill, which has not been diluted with maceration, be regarded as the Brix of the absolute juice.

Under these conditions it was expected that the Brix of this juice would be higher than that of the crusher, for the crusher juice was already diluted with flume water.

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* A report of a committee selected to study this question and to make recommendations to the 1934 group meeting of field men and others on the Island of Hawaii.

The following eighty-nine samples were therefore taken:

10 samples crusher	Brix 14.75	Samples bag. roll 1st mill	Brix 14.63
8 " "	" 15.83	" " " " "	" 15.56
10 " "	" 14.68	" " " " "	" 14.19
9 " "	" 15.68	" " " " "	" 14.73
20 " "	" 15.59	" " " " "	" 15.28
12 " "	" 15.56	" " " " "	" 15.14
20 " "	" 15.32	" " " " "	" 14.73

The average being 15.36 for crusher samples, and 14.91 for the bagasse roll of the first mill.

These tests seem to show that this method is not of much value, as the Brix of the eighty-nine samples of the crusher juice was higher than that of the bagasse roll juice of the first mill. Sometimes, however, the reverse of this is true.

Walter E. Smith comments on this method as follows:

These tests comparing crusher juice with first bagasse roll juice can only be accounted for on the basis that the light pressure of the crusher is not sufficient to express any appreciable amount of this water out of the wet trash, and that a large part is therefore expressed later by the bagasse roll of the first mill.

How else could you account for the lower Brix of the first mill bagasse roll juice? And if this is so, does it follow that the crusher sample is being materially diluted, or rather, more so than the first mill juice?

Experiment 2.

The second experiment was based upon the fact that, provided flume water was carried over into the juice by the field trash only, i. e., by absorption, and the rest of it was drained off the steel slat carrier, it was possible to estimate the amount absorbed by the field trash, and thus possibly correct the error by calculations. Twenty-four samples of cane with their accompanying trash were therefore taken from the flumes as they travelled from the field to the cane carrier, and the wet field trash was weighed, including cane tops, leaves, and borer-eaten cane.

These samples of field trash were then sun dried, and weighed again; the following are the results:

Water of absorption, 55.00, 50.29, 69.08, 72.40, 72.22, 58.38, 77.31, 71.93, 63.44, 65.58, 63.72, 71.91, 63.47, 75.00, 61.24, 75.70, 46.30, 56.51, 38.40, 39.00, 78.00, 71.59, 43.89, 52.90.

An *average* of 61.22 per cent water absorbed by field trash.

Mr. Smith comments on this method as follows:

If we assume that the field trash is carrying into the mill certain amounts of water, this water will not be entirely expressed into the crusher juice unless the wet field trash is reduced to the same moisture content as that found for this field trash after it has been sun dried.

It would appear quite unlikely that this is the case, as material leaving the crusher is quite obviously wetter than sun dried field trash. Furthermore, the amount of water actually expressed will vary with the quality of ~~the~~ crusher work, being more when the crusher is well loaded, and less with a light load and low crushing performance.

Hence, it would appear difficult to assume that the amount of dilution of the crusher juice was actually equal to the amount of water of absorption carried into the mill by the field trash.

The more I puzzle over this problem, the more hopeless it appears to me to arrive at any relatively simple method of estimating the effect of the water of absorption, and should hesitate to say specifically that this method would give a very positive way of correcting for water.

Experiment 3.

The third, and final, experiment is based upon the fact that where a sample of uncleaned, wet cane is flumed over a cane carrier, especially if the carrier is of the steel slat type, the Brix of the first expressed juice crushed from this cane is lower than the Brix of the juice from the same sample of cane when it is dry and cleaned of all field trash.

Four varieties of cane were subjected to this test as follows:

	Brix	Pol	Pur.	Q. R.	Juice Factor	% Field Trash	% Dil.
Yellow Caledonia							
Cleaned cane	17.42	15.60	89.55	8.40	......	None	.....
Uncleaned cane	16.02	14.13	88.20	9.44	108.74	8.85	8.03
D 1135							
Cleaned cane	16.26	14.59	89.73	9.00	......	None	.....
Uncleaned cane	13.56	11.99	88.42	11.00	119.91	12.16	16.61
P. O. J. 36							
Cleaned cane	15.86	14.22	89.66	9.20	......	None	.....
Uncleaned cane	13.66	11.97	87.63	11.10	116.11	14.90	13.87
P. O. J. 213							
Cleaned cane	16.62	15.26	91.82	8.45	......	None	.....
Uncleaned cane........	13.49	11.89	88.14	11.20	123.20	12.50	18.83

In the above data, it will be seen that: The Brix and purity of the juice from the cleaned cane is higher than that of the uncleaned cane; also the quality ratio is lower in case of the cleaned cane; and in order to correct the error for the dilution, a juice factor from 108.74 to 123.20 must be used; the field trash varied from 8.85 to 14.90, and the dilution from 8.03 to 18.83 per cent.

Mr. Smith comments on this method as follows:

In this experiment showing the effect of field trash and its accompanying water, the percentage of field trash in all cases is rather high, 8.8 per cent, 12.16 per cent, 14.9 per cent and 12.5 per cent.

In these instances the dilution effect is quite high—but in the final analysis, is it not apparent that such high field trash figures are very undesirable, and that they represent an abnormal condition which should be corrected from other standpoints?

In these tests the juice purity is depressed from 1.3 to 2.0 points by the field trash. While in all cases the introduction of the field trash has also introduced water, which dilutes the juices, it is obvious that some non-sugars must also have been introduced to reduce the purity. Obviously no sucrose is added, so that from an initial ton of sucrose in juice, to depress the purity two points, we must also introduce 45 pounds of non-sugar solids.

At about 33 purity of waste molasses, this means a loss of 15 pounds of sucrose per ton of sucrose in juice; an item, of course, of considerable importance.

It does seem, therefore, that by making a series of tests as outlined under the Experiment 3 method, it might be possible to obtain a series of factors to apply for different

varieties and various amounts of field trash. These could at best be only approximate, but might be better than our present methods.

In conclusion, your Committee suggests that out of the three tentative methods suggested, Experiment 3 may be used in determining a factor for correcting the error in the density of the first expressed juice, due to fluming water being carried over a cane carrier into the first expressed juice.

On Setting the Crest Elevation for the Parshall Flume

By H. A. Wadsworth

The increasing local interest in the Parshall Flume as a means of measuring irrigation water has prompted a brief study of the conditions governing the most desirable elevation of the crest under field conditions. In ditches on flat grades this elevation is most critical. If too low the structure will become submerged thus requiring two gage readings in place of one, as well as troublesome arithmetical manipulations after the readings are secured. If set too high the water in the ditch will back up, increasing water losses and possibly endangering the ditch banks. The purpose of this note is to outline a procedure by which the proper elevation may be determined before the construction of the device is begun. Relocating a flume to avoid either of these difficulties may double its cost.

In its most comprehensive form the Parshall Flume is equipped with two gages. One of these is in the intake section, the point of measurement being one-third of the distance from the intake to the throat. The depth of water above the level floor of the intake section at the upper gage is called H_a and is the gage height given for varying discharges in the standard free-flow tables. The other measuring station, not often provided for particularly in local installation, is at the downstream end of the throat, the opening into the stilling well being three inches above the bottom of the depression in the floor and two inches upstream. Gage heights in this well are measured on a gage or rule set with its zero reading on the plane of the floor produced. This gage reading is known as H_b. The locations of these gages and their datum plane are shown in the figure.

It was soon found that in most installations the gage reading at H_b was unnecessary since H_a was a direct function of the discharge. This aspect of the flume's performance is called "free-flow." Most, if not all, the flumes in the Islands enjoy free-flow conditions; consequently only one gage is necessary and only one provided.

Under unsatisfactory conditions of installation the stream fails to get away from the structure fast enough to permit this desirable condition. In such cases the water in the diverging section may be crowded back into the throat section, producing what is known as a "standing wave" or "hydraulic jump." When the water in the stilling well at H_b has risen to "zero" on gage H_b, the structure is said to be submerged but the degree of submergence is zero and no harm is done. Increased obstruction in the get-away causes an increase in H_b and the degree of submergence increases. The magnitude of submergence is measured by dividing the head at H_b by H_a. This fraction is expressed as a per cent. As an example, if H_a equals 1.70 feet and H_b equals 0.92 foot the submergence is said to be 54 per cent.

One of the virtues of the Parshall Flume is that the gage reading at H_a is a direct measure of the discharge until the percentage of submergence becomes 70 per cent for flumes of ordinary size. Further increase in H_b is reflected in an increase in H_a, although there may be no increase in discharge. Consequently,

the discharge secured by using the table in the usual way in such cases is greater than the true discharge by an amount which is a function of the degree of submergence.

Although the quantity to be subtracted from the tabular discharge can be computed with fair precision if the degree of submergence is known, the operation is time consuming. Moreover two water-stage registers would be required for a continuous record of the discharge performance of any flume experiencing a greater degree of submergence than 70 per cent.

Consequently, local flumes are ordinarily set high enough that this maximum tolerable submergence will not be exceeded.

The proper elevation of the floor of the flume depends upon:

(1) The maximum amount of water to be measured.

(2) The depth of water in the ditch when this quantity of water is being delivered.

(3) The size of the flume.

(4) The loss of head resulting from any particular combination of discharge and flume size.

(5) The permissible degree of submergence for free-flow conditions in view of the size of flume used. As indicated this may be taken as 70 per cent except for flumes with a width of less than one foot.

"Cut and try" methods can best be used in deciding on the crest elevation for certain conditions. Suppose a ditch carries a maximum flow of 8.5 M.G.D. or, say, 13 c.f.s. and that the depth of water in the ditch at the proposed point of installation is 2.0 feet when this quantity is being delivered; the problem lies in establishing the elevation of the crest somewhere within this 2.0-foot range so that

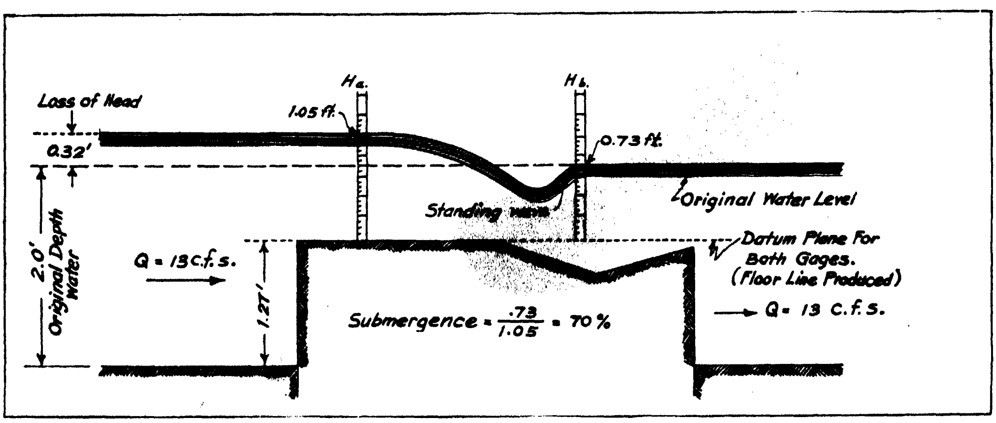

Fig. 1. Diagrammatic sketch of a three-foot Parshall flume carrying 13 c.f.s. Note relative position of gages.

the water level in the ditch below the device may keep its normal position and still allow free-flow conditions. It is hydraulically impossible to install a flume without the water standing at a higher elevation above the flume than it did originally. This difference is called the "loss of head" and on flat grades must be kept at a minimum.

At least four flume widths suggest themselves upon consulting the discharge tables. One of these is the three-foot flume. If this flume be used, H_a would

be 1.05 feet. Since a submergence of 70 per cent is permissible, it is evident that the gage reading at H_b may be (1.05 x 0.70) or 0.73 foot without violating free-flow conditions. Since both gages stand on the same datum plane, the loss of head due to the structure would be (1.05-0.73) or 0.32 foot. Since the depth of water in the ditch below the device must be 2.00 feet according to the assumption, it follows that the depth of water above the device at maximum discharge would be 2.32 feet in view of the head lost at this flow. The reading of head at H_a is the distance between the floor of the flume and the upstream water level. Consequently, since H_a = 1.05 the floor should be set 1.27 feet (or 2.32 minus 1.05) above the bottom of the ditch.

In tabular form these data and those for other flume sizes appear as follows:

Flume Size in Feet	Q	H_a	H_b*	Maximum Loss of Head	Necessary Upstream Depth	Elevation of Floor Above Ditch Bottom†
3.0	13.0	1.05	0.73	0.32	2.32	1.27
4.0	13.0	0.88	0.62	0.26	2.26	1.38
5.0	13.0	0.76	0.53	0.23	2.23	1.46
6.0	13.0	0.68	0.48	0.20	2.20	1.52

* Based on a permissible submergence of 70 per cent. $H_b = H_a \times 0.70$.

† Difference between necessary upstream depth and H_a.

These relations for the three-foot flume are shown in the figure.

With such a table available one is able to consider the other factors which may affect the installation. For flows which are essentially constant the use of the smallest flume would be most desirable, partly because of the economy of construction but also because of its increased sensitivity to minor variations of flow.

Some plantation ditches experience freshet flows in which the normal capacity is far exceeded. In such cases a larger flume than is normally required may be used or the side walls may be extended vertically to care for the excess head. According to Mr. Parshall the extrapolation of the discharge tables to include these occasional heads seems justified. Such extrapolations for the most frequently used flume sizes are available at the Experiment Station H.S.P.A. Regardless of the policy used with respect to flood-flow, the elevation of the crest may be determined by the procedure given above.

In general, plantation flumes are not submerged to the degree indicated. Mr. Parshall after exhaustive tests has concluded that free-flow conditions exist at 70 per cent submergence for all flumes of one foot or larger in size. For flumes smaller than one foot, the permissible submergence for free-flow is 60 per cent. Agriculturists who plan to use a maximum submergence of less than 70 per cent will naturally make the required modification of the form given in the table.

The Sugar Industry of Mauritius*

The island of Mauritius, of volcanic origin, athwart the southeast trade winds has a relief consisting of mountains, plateaus and coastal plains, and a rainfall heavy on the windward highlands and lighter on the leeward side. The island is occasionally visited by tropical cyclones.

Sugar cane culture, introduced into Mauritius in 1650, was considerably extended about 1744 when new strains were introduced. Between 1845 and 1863 impetus was given to the industry by the introduction and use of laborers from India. The period 1863 to 1895 was one of retrogression due to the successful competition of beet sugar which lowered the price, and to the occurrence of two calamitous cyclones. The industry recovered, a gradual increase in output due to improved methods of cultivation occurred, and in 1914 production reached a peak of 289,300 tons†, the record output for Mauritius. The year 1924 marked the beginning of a period of decline in the industry due to a fall in the price of sugar. The area used for the crop diminished and in some districts the Indians gave up the raising of sugar cane for market gardening.

More than forty varieties of sugar cane are raised on Mauritius. At the beginning of the twentieth century the three most common were the two Big-Tanna (white and striped), and MP55, the seed of which came from Penang. White Big-Tanna, the standard variety, has been attacked by disease, and P. O. J. 2878, a very hardy and disease-resistant strain from Java, has been introduced.

Antiquated agricultural methods in the industry have been given up for modern usages in which machinery and fertilizer play an important part. Four or five ratoon crops are harvested at intervals of twelve or thirteen months. Harvesting takes place in September, October, and November. Cut cane is carried from the fields to the mills on narrow-gauge railways. The average yield is 18 to 19 tons an acre. The yield is much greater on large plantations than on small farms, but the latter afford indisputable moral and social advantages to the proprietors, mostly Indians, and tend to increase.

In the early days of the sugar industry in Mauritius the extraction of sugar was distributed among many small mills, as many as 227 in 1854. With the development of better technique in milling their number gradually decreased and in 1925 only 47 were in operation. In 1925, twenty mills manufactured more than 5000 tons of sugar each and twenty-seven between 5000 and 2500 tons.

Most of the sugar companies own large plantations and grind their own cane and also that of small farmers. They also compete with one another in buying cane for their mills as a result of which there evolve delicate questions of relationships between big and small planters, especially since the mills with their improved

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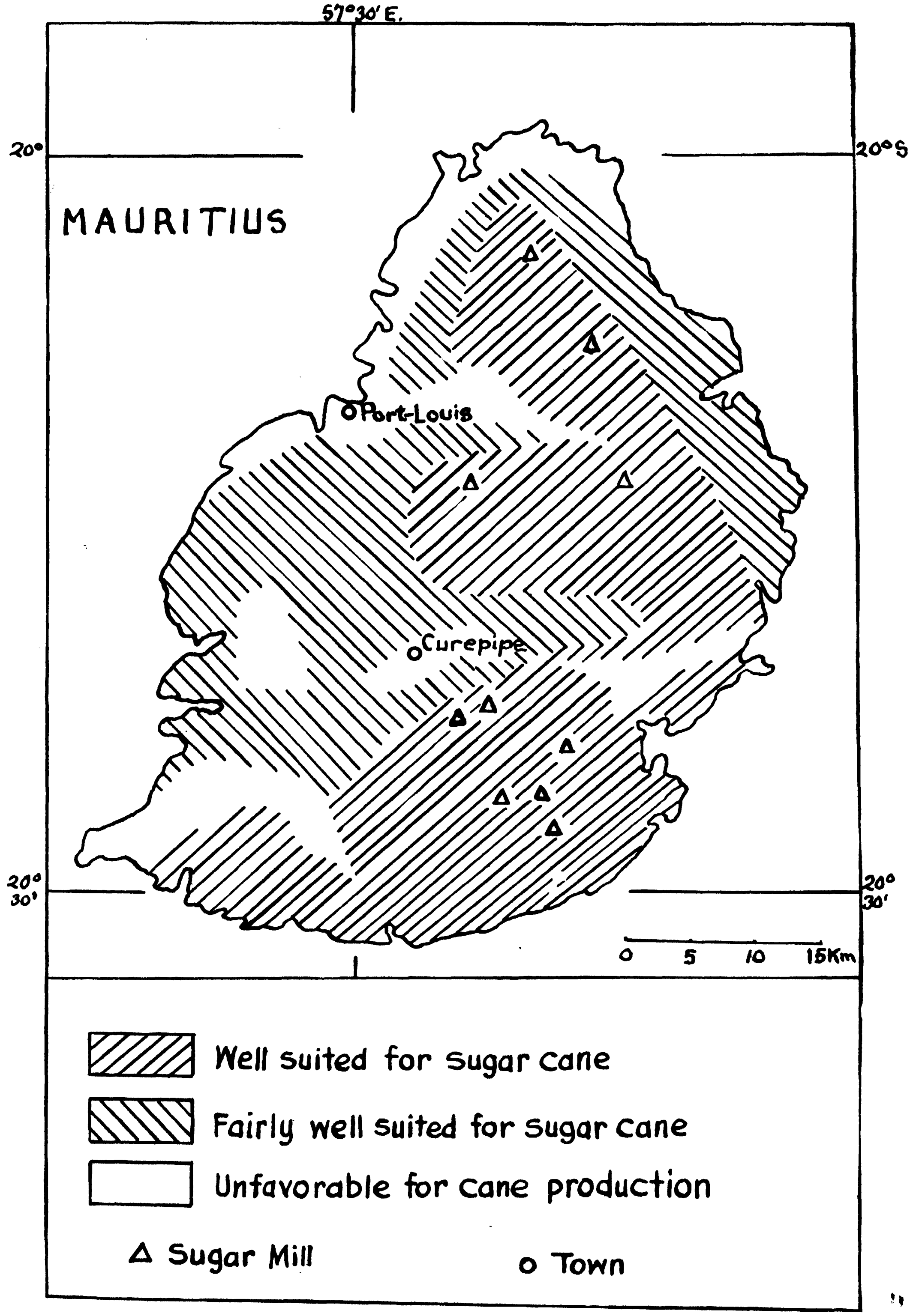
*** The sugar industry on the island of Mauritius (about 20° S. lat. and 57° 30′ long.) is affected by conditions in many ways similar to those on the island of Oahu. This article is an abstract by J. W. Coulter (Dept. Geog., Univ. Hawaii) of an account of the sugar industry on Mauritius, by Paul Caubet, in *Annales de Geographie*, September, 1933, pp. 516-528.**

† This seems to be long tons (2,240 pounds).


57°30' E.
20°
20°S
MAURITIUS
Port-Louis
Curepipe
20° 30'
20° 30'
0 5 10 15Km
Well suited for sugar cane
Fairly well suited for sugar cane
Unfavorable for cane production
Sugar Mill
Town

types of machinery can grind nearly twice as much sugar cane as is supplied to them. The average extraction of sugar is about 11 per cent by weight.

The distillation of rum from molasses, once a very important industry in Mauritius, has declined to very small proportions for the following reasons: (1) the closing of the market in Madagascar by a prohibitive duty, (2) an increase in freight rates to markets in London and eastern Africa, (3) an increase in the local excise duty, and (4) a rise in price of molasses.

Sugar makes up more than nine-tenths of the exports of Mauritius. India was formerly the principal market but now England takes four-fifths of the output allowing the island a preferential tariff. There have been great fluctuations in price. A low price at present coincides with an increase in cost of production as a consequence of which there is great uneasiness among producers.

The conclusion at which Caubet arrives from his study is that the production of sugar will remain the basic industry of Mauritius. Although the immediate post-war profits are not likely to obtain again, prices in the future will remain relatively stable. Improvements must be made in the agricultural aspects of the industry comparable with those in the mills. The subdivision of holdings for the benefit of immigrant Indians is bringing about a situation which involves in the future the solution of social problems just as important as economic phases of the industry.

Soil Terminology

Present-day interest in studying the soils of the individual fields of the plantation and adapting the fertilization to their special needs, brings about renewed interest in soil classification and soil terms that bear upon it.

At the First International Congress of Soil Science, which was held in Washington, D. C., during 1927, C. F. Shaw of the University of California, who was chairman of the Committee on Nomenclature of the American Soil Survey Association, presented a glossary of terms used in soil literature, using the following introduction when submitting his report:

Many of the terms now used in soil literature are given different meanings by writers in different countries and even by different authors within one country. This causes much confusion and it seems desirable to attempt to reach an agreement on definite interpretations of the terms in general use.

As chairman of the committee on Nomenclature of the American Soil Survey Association, the writer has compiled a glossary of terms used in soil classification and the soil survey. These terms and their definitions have been compiled from lists submitted by members of the Soil Survey Association and from a study of published soil surveys and papers dealing with soil classification. The definitions of the terms have been carefully phrased in an endeavor to express the meaning that has been established by general use and custom. Only a few terms that apply solely to the laboratory phases of soil science have been included; most of them apply to soil classification and the characteristics of the soil in the field.

It is not expected that all the definitions will be acceptable to all soil scientists, but it is hoped that most of the terms will be approved as defined and that those with debatable meanings will be discussed and a definite meaning for each term ultimately agreed upon.

General Terms

Soil: The soil is a natural body occupying the surface portion of the Earth, composed of mineral and organic materials and having more or less definitely developed horizons of eluviation and illuviation.

This term soil, as defined, includes both the Solum and the upper portion of the parent material, the A, B and C horizons.

Solum: The weathered portion of the soil mass including the full depth to which eluviation and illuviation are in evidence. The A and B horizons.

Parent Material: The slightly altered or wholly unweathered material beneath the solum, similar to that from which the soil was formed. The C horizons.

Eluviation--Eluvial: A process of removal by percolating waters of material in solution or in suspension. Horizons from which material has been removed by eluviation.

Illuviation—Illuvial: A process of accumulation by deposition from percolating waters of material transported in solution or suspension. Horizons in which material has been deposited by illuviation.

Soil Fertility: The capacity of a soil for production under favorable conditions.

Soil Productiveness: The actual producing power of a soil under the normally existing conditions.

Soil Characteristics: Distinguishing qualities, properties or features that may serve to establish the character of a soil.

Organic Matter (of the Soil): The more or less decomposed material of the soil derived from organic sources, usually from plant remains.

The term organic matter covers such material in all stages of decay and is recommended as a better term than ''humus'', which though in general use, is indefinite and poorly defined.

Humus: A more or less stable stage in the decomposition of organic matter in the soil. The organic matter that can be extracted from a soil by dilute alkali after treatment with dilute hydrochloric acid.

This term is quite indefinite in application and also in an analytical sense. It is better to use the more general term "organic matter" when referring to the organic content of the soil.

Claypan: An horizon of accumulation or a stratum of stiff, compact and relatively impervious clay.

The claypan is not cemented, and if immersed in water can be worked to a soft mass. Its presence may interfere with water movement or root development as does a true hardpan. It is more difficult to overcome for whereas a hardpan can be shattered by explosive the claypan, after breaking by any means, will run together and reform as soon as thoroughly wetted. The distinction between the hardpan and the claypan is an important one in the soil classification.

Hardpan: An horizon of accumulation that has been thoroughly cemented to an indurated, rock-like layer that will not soften when wet.

The term "hardpan" is not properly applied to hard clay layers that are not cemented, nor to those layers that may seem indurated when dry but which soften and lose their rock-like character when soaked in water. The true hardpan is cemented by materials that are not readily soluble, and is a hard layer that definitely and permanently (in nature) limits downward movement of roots and water.

Soil Genesis

Mineral Soils: Soils composed mainly of inorganic (mineral) material with relatively low contents of organic material.

Organic Soils: Soils composed mainly of organic material; the organic content being sufficient to dominate the soil characteristics.

Sedentary Soil: Soils formed in place without the addition of transported material.

Residual Soil: Sedentary soils formed by the weathering of mineral material.

Cumulose Soil: Sedentary soils formed by the accumulation of more or less decayed organic remains. Organic soils.

Peat Soil: Soil composed predominantly of organic material, considerably decomposed but highly fibrous, with easily recognizable plant remains.

Muck Soil: Soil composed of thoroughly decomposed organic material, with a considerable amount of mineral soil material, finely divided and with few fibrous remains.

Primary Soils: Soils developed through the disintegration and decomposition of rocks in place and the weathering of the resulting debris to true soils with definite horizons of eluviation and illuviation. Residual soils.

Secondary Soils: Soils developed through the weathering of materials, originating from previously existing soils and from rock debris, that have been eroded from their former locations and redeposited by the transporting agents. Transported soils.

Transported Soils: Soils formed by the consequent or subsequent weathering of materials transported and deposited by some agency such as water, air, ice, etc. Secondary soils.

Alluvial Soil: Soil formed from materials transported by flowing waters and deposited as alluvial fans and flood plains.

Marine Soil: Soil formed from materials deposited by the waters of oceans and seas, exposed by elevation of the land or the desiccation of the sea.

They are usually characterized by the commingling of sediments of different sizes that are not found in the deposits of any other agency except glaciation.

Aeolian Soil: Soil formed from materials transported and deposited by air.

This group includes not only the areas of wind-blown sand usually associated with sand dunes, but also the large areas of fine textured materials that have been wind deposited or wind modified since deposition, such as the wind modified deposits of fine volcanic ash, etc.

Soil Profile

Profile—Soil Profile: A Soil Profile is a vertical section of the soil from the surface to the underlying unweathered material.

Normal Profile: A characteristic profile developed under relatively uniform conditions of weathering.

Abnormal Profile: A profile departing from the Normal Profile conditions in some important respects, by reason of some unusual change in the factors governing weathering.

Abnormal profiles might be caused by excessive erosion following the removal of vegetative cover by fires, by changes in drainage conditions due to natural or artificial causes, or by any action which might change the natural conditions governing weathering.

Color Profile: A profile divided into horizons on the basis of color.

Chemical Profile: A profile divided into horizons on the basis of chemical composition.

Structural Profile: A profile divided into horizons on the basis of structure.

Textural Profile: A profile divided into horizons on the basis of texture.

Horizon—Soil Horizon: A layer or section of the soil profile, more or less well defined, and occupying a position approximately parallel to the soil surface.

Stratum—Strata: A layer or layers of material whose character was established during formation and is not due to subsequent alteration by weathering.

In transported soils there may be layers or strata of sand, clay, gravel, or other textures, of varying conditions with respect to structure and consistence, that may have an important bearing on the character of the soil, even influencing the effects of weathering agents. Hence in these definitions reference is made both to horizons and strata.

Horizon A: The upper horizon of the soil mass, from which material has been removed by percolating waters. The horizon of eluviation. The "surface" soil.

This horizon is generally subdivided into two or more sub-horizons, of which A_0 is not a part of the mineral soil, but is the accumulation of organic debris upon the soil surface. Other sub-horizons are designated as A_1, A_2, etc.

Horizon B: The horizon of deposition, to which materials have been added by percolating waters. The horizon of illuviation. The "subsoil."

This horizon may be divided into several sub-horizons, depending on the color, structure, consistence or the character of the material deposited. These sub-horizons are designated B_1, B_2, B_3, etc.

Horizon C: The horizon of relatively unweathered material underlying the B horizon. The "substratum."

The C horizon, while often described as "unweathered", usually shows some modification in the upper portions and may have one or more sub-horizons. In most cases it represents the "parent material" similar to that from which the soil was formed. In some cases it may be a stratum or geological formation of different material.

Surface Soil: The upper horizon or surface layer of the soil mass. The horizons above Horizon A_2.

In describing cultivated soils, it usually includes that portion that is modified by plowing and other tillage operations. In other cases, where the color of the upper portion of the soil mass is modified by accumulations of organic matter, it is applied to the full depth of that color horizon.

Subsurface Soil: The horizon or layer of soil directly beneath the surface soil. The A horizons below Horizon A_1.

In cases where the term "Surface Soil" is applied to the tilled portion of soils that are deep and uniform, it is used to include the portion of the uniform material below the tilled depth.

Subsoil: The horizons or layers of soil beneath the surface soils. The B horizons.

When necessary, the subdivisional terms upper subsoil, lower subsoil, etc., are used.

Substratum: The horizons or layers of material below the solum or true soil mass. The C horizons.

In most cases the substratum is the parent material. In some soils, it may be materials quite distinct in character from that which weathered to form the overlying soil mass. In

Recent soils, where distinct A and B horizons may not exist, it usually is applied to strata distinctly different in color, texture, structure or consistence from the upper or "soil" layers.

Soil Development

Recent Soil: A soil having a profile without definite horizons of eluviation or illuviation; relatively unweathered recent or very immature soil.

Recent soils usually are secondary soils composed of recently deposited transported materials, there being no evidence of any downward migration of clay, lime or other material, no evidence of differences in the degree of weathering of the minerals at any varying depths and no indication of any changes in structure of the soil.

Young Soil: A soil having a profile with slightly compact subsoil horizons, but without distinct clay accumulations; slightly weathered immature soil.

Immature Soil: A soil having a profile with compact subsoil horizons with distinct clay accumulations; moderately weathered immature soil.

Mature Soil: A soil having a profile with a compact highly colloidal dense clay horizon or with a cemented rock-like hardpan horizon; fully weathered mature soil. The end product of weathering under the existing conditions. A climax soil.

Soil Classification

Soil Type: A soil which throughout the full extent of its occurrence has relatively uniform texture of the surface soil and relatively uniform profile characteristics. The unit of soil mapping.

The name of the soil type is a combination of series name and the textural grade designation, as for example—Orangeburg sandy loam.

Phase: A subdivision of the "Soil Type" covering departures from the typical soil characteristics, insufficient to justify the establishment of a new type, yet worthy of recognition.

The phase subdivision is used when the deviation from the typical may be insufficient to warrant the establishment of a new type, or when the areal extent of a major variation is too small to warrant its independent recognition, yet where it is desirable to show the location and extent of the atypical material on the map and in the report. Phase variations may cover color, texture, structure, topography, drainage, or any other feature of deviation from the typical.

Soil Series: A group of soils having the same character of profile (the same range in color, structure, consistence, and the same sequence of horizons and degree of horizontal development), the same general conditions of relief and drainage and usually a common or similar origin and mode of formation. A group of soil types closely similar in all respects except the texture of the surface soils.

Soil Family: A group of soil series that are progressing toward a common or closely similar final mature profile condition.

The "Family" would include all soils regardless of their stage of development, that were progressing toward the same mature profile characteristics, and would indicate an existence, for different periods of time, under uniform and similar conditions of climate, vegetative cover and drainage. It might also indicate a common origin and mode of formation.

Soil Order: A grouping of soils on the basis of the character of the soil mass—as mineral or organic.

(A new term used only by the author.)

Physical Characteristics of Soils

Soil Texture: Texture is a term indicating the coarseness or fineness of the soil mass; the combined or mass effect of the different sizes and quantities of individual grains or particles making up the soil.

As the soil is usually made up of particles of widely varying size, the textural terms usually express the average effect or the combined effect of all these grain sizes, but they may indicate the predominance (in quantity or in textural effect) of a certain group of grains.

The textural composition is determined by mechanical analysis—a laboratory process of separating the soil into groups of grain-sizes. The system of mechanical analysis used by the Bureau of Soils of the United States Department of Agriculture separates the soil into seven grain-sizes or "separates" having the following size and name:

	mm.
Fine gravel	2. —1.
Coarse sand	1. —0.5
Sand	0.5 —0.25
Fine sand	0.25 —0.10
Very fine sand	0.10 —0.05
Silt	0.05 —0.005
Clay	0.005— ?

Sands contain less than 20 per cent of silt and clay.

Sandy Loams contain from 20 to 50 per cent of silt and clay but do not have over 20 per cent of clay.

Loams have more than 50 per cent of silt and clay combined but have less than 50 per cent of silt and less than 20 per cent of clay.

Silt Loams have more than 50 per cent of silt and less than 20 per cent of clay.

Clay Loams have more than 50 per cent of silt and clay combined but less than 50 per cent of silt and between 20 per cent and 30 per cent of clay.

Clays have more than 50 per cent of silt and clay combined and more than 30 per cent of clay.

Textural Grade: A classification of soils based on texture alone.

This has been called the "class" in many soil publications.

In the field texture is determined by the feel of the soil mass when rubbed between the fingers. The following statements give the obvious physical characteristics of the basic textural grades:

Sand: Sand is loose and single-grained. The individual grains can readily be seen or felt. Squeezed in the hand when dry it will fall apart when the pressure is released. Squeezed when moist, it will form a cast but will crumble when touched.

Sandy Loam: A sandy loam is a soil containing much sand but which has enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart, but if squeezed when moist a cast can be formed that will bear careful handling without breaking.

Loam: A loam is a soil having a relatively even mixture of the different grades of sand and of silt and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling, while the cast formed by squeezing the moist soil can be handled quite freely without breaking.

Silt Loam: A silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay, over half of the particles being of the size called "silt". When dry it may appear quite cloddy but the lumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together and puddles. Either dry or moist it will form casts that can be freely handled without breaking, but when moistened and squeezed between a thumb and finger it will not "ribbon" but will give a broken appearance.

Clay Loam: A clay loam is a fine textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin "ribbon" which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact mass.

Clay: A clay is a fine textured soil that usually forms very hard lumps or clods when dry and is quite plastic and usually sticky when wet. When the moist soil is pinched out between the thumb and fingers it will form a long, flexible "ribbon". Some fine clays very high in colloids are friable and lack plasticity in all conditions of moisture.

Gravelly or Stony Soils: All of the above grades of soil, if mixed with a considerable amount of sand, gravel or stone, are designated as sandy clay loams, sandy clays, etc., as gravelly sandy loams, gravelly clays, etc., or as stony sandy loams, stony loams, etc.

Soil Separate: One of the several grain-size groups into which the soil is separated by mechanical analysis.

Colloid—Colloidal: Particles of colloidal size (below 1_u diameter) present in sufficient amount to have an appreciable effect on the soil character.

Heavy (Textured): Applied to soils of fine texture in which clay predominates, with dense structure and firm to compact consistence.

The term is also applied to soils containing a somewhat higher proportion of the finer separates than is typical of that textural grade (as a "heavy sandy loam").

Light (Textured): Applied to soils of coarse to medium texture with very low silt and clay content, incoherent, single-grained structure, and loose consistence.

The term is also applied to soils containing somewhat higher proportions of the coarser separates than is typical of that textural grade (as a "light loam").

Sharp: Containing angular particles in sufficient amount to dominate the "Feel". Abrasive.

Gritty: Containing a sufficient amount of angular grains of coarse sand or fine gravel so that these dominate the "feel". Usually applied to medium textured soils (loams) where the actual quantity of these coarse grains is quite small.

Smooth: Containing well rounded coarser particles and a predominance of the finer separates. Not abrasive.

Velvety: Very smooth textured, free from any coarse particles, usually free from any except the smallest aggregates.

Floury: Fine-textured soil consisting predominantly of silt (or flocculated clay with aggregates of silt size) which when dry is incoherent, smooth and dust-like.

POROSITY

Soil Porosity: Porosity is a term indicating the mass effect of the pores or voids between the individual particles and aggregates that make up the soil.

Porous: A soil having a maximum of voids or pore spaces.

Dense: A soil having a minimum of pore space and an absence of any large pores or cracks.

STRUCTURE

Soil Structure: Structure is a term expressing the arrangement of the individual grains and aggregates that make up the soil mass.

The structure may refer to the natural arrangement of the soil when in place and undisturbed or to the soil at any degree of disturbance. The terms used indicate the character of the arrangement, the general shape and the size of the aggregates and in some cases may indicate the consistence of these aggregates.

Crumb-Structure: Porous aggregates of irregular shape, rarely over 2 cm. in diameter and of a medium to soft consistence.

Fine Crumb—Crumbs 5 mm. or less in diameter.

Coarse Crumb—Crumbs 2 cm. or more in diameter.

Mealy: A crumb-like structure where the aggregates are of soft to very soft consistence and usually less than 5 mm. in diameter.

Granular: Aggregates varying in size to 2 cm. in diameter, of medium consistence, and more or less subangular or rounded in shape.

Fine Granular: Aggregates under 5 mm. diameter.

Coarse Granular: Aggregates close to maximum size.

Buckshot: Aggregates of roughly spherical shape, usually 2 or 3 mm. in diameter, and of a hard consistence.

Lump (Lumpy): Aggregates of irregular shape, of medium to hard consistence and from 2 to 10 cm. in diameter.

Clod (or Cloddy): Aggregates of irregular, angular shape, usually 8 cm. or more in diameter and of a hard consistence.

Fine Cloddy—When most of the clods are close to the minimum size (8 to 12 cm.).

Coarse Cloddy—When most of the clods are 20 cm. or more in diameter.

Adobe: A soil which on drying cracks and breaks into irregular but roughly cubical blocks. The cracks are usually wide and deep and the blocks are from 20 to 50 or more centimeters across. (Adobe soils are usually heavy-textured and high in content of colloidal clay.)

Structureless: Without any discernible structure or arrangement of the soil particles into aggregates.

Puddled: A condition of massive structure brought about when by artificial or natural action the previously existing structures are broken down and destroyed. Deflocculated.

Pulverulent: The soil reduced to a mass of soft crumbs and granules.

Fluffy: A surface condition where the aggregates are loose, of light weight and fine texture, with no cohesion or evidence of arrangement; floury.

Mulch (or Mulched): An horizon with a loose, incoherent arrangement of aggregates of mealy, crumb or granular structure.

Crust (or Crusted): Where the upper or surface horizon coheres into plate or crust distinct from the horizon immediately below it.

TILTH

Soil Tilth: Tilth is a term indicating the condition of soil structure brought about by manipulation; an artificial structure produced by tillage or cultivation.

Terms indicating the condition of tilth are the same as those indicating the soil structure under the broken or disturbed conditions, as mealy, pulverulent, granular, crumb, buckshot, mulch, nut-structure, cloddy.

CONSISTENCE

Soil Consistence: Consistence is a term expressing the degree of cohesion of the soil and the resistance opposed to forces tending to deform or rupture the aggregates.

Consistence and structure are closely related and frequently interdependent. The terms expressing consistence and structure are distinct, however, and need not be confused or used with double meaning.

Loose: A soil with particles or small aggregates that are independent of each other or are very weakly cohering, with a maximum of pore space and a minimum resistance to forces tending to cause rupture.

Soft: A soil that yields readily to any force causing rupture or deformation. Aggregates readily crushed between fingers.

Mellow: A soil with particles or aggregates that are weakly adhering in a rather porous mass, readily yielding to forces causing rupture. A consistence softer than friable. Without tendency to pack.

Friable: A soil with aggregates that can be readily ruptured and crushed with application of moderate force. Easily pulverized or reduced to crumb or granular structure.

Firm: A soil resistant to forces tending to produce rupture or deformation. Moderately hard. Aggregates can be broken between fingers.

Compact: A soil that is dense and firm, but without any cementation. Quite resistant to forces tending to cause rupture or deformation. Coherent.

Relative degree of compactness can be expressed by terms as slightly compact, very compact, etc.

Hard: A soil resistant to forces tending to cause rupture or deformation. Difficult or impossible to crush aggregates with fingers only.

Brittle: A soil which when dry will break with a sharp, clean fracture. If struck a sharp blow, it will shatter into cleanly broken hard fragments.

Plastic—Plasticity: A soil readily deformed without rupture. Pliable but cohesive. Can be readily moulded. Putty-like.

Cheesy: A soil having a more or less elastic character, deforming considerably without rupture, yet broken without difficulty or the application of much force.

Characteristic of certain highly colloidal soils when thoroughly wet.

Sticky: A soil that shows a decided tendency when wet to adhere to other materials and foreign objects.

Tenaceous: A soil that shows a decided resistance to rupture. The soil mass coheres firmly.

Sticky and Tenaceous are often used as synonyms, but in soil usage the former is taken to refer to adhesion, the latter to cohesion. Both may be present in a soil at the same time.

Stiff: A soil that is resistant to rupture or deformation. A soil stratum or horizon that is firm and tenaceous, and tending toward impervious.

Usually applied to condition of the soil in place and when moderately wet.

Tight: A term applied to strata or horizons of the soil that are compact, impervious and tenaceous and usually plastic.

Tough: A soil that is resistant to rupture. Tenaceous. A term applied to strata or horizons of the soil that can be readily bored into with the auger but which requires much force in breaking loose and pulling out the core of soil.

Impervious: A soil very resistant to penetration by water and usually to air and to plant roots. Impenetrable.

In field practice the term is applied to strata or horizons that are very slowly penetrated by water and that retard or restrict root penetration. Relatively Impervious or Slowly Pervious are better expressions.

Cemented—Cementation: A condition occurring when the soil grains or aggregates are caused to adhere firmly and are bound together by some material that acts as a cementing agent (as colloidal clay, iron, silica, or aluminum hydrates, lime carbonate, etc.).

Chemical Characteristics

Calcareous Soil: A soil containing sufficient calcium carbonate to effervesce when tested with weak 0.1 N hydrochloric acid.

In accordance with the amounts present, these soils may be designated as slightly calcareous, strongly calcareous, etc.

Acid Soil: A soil that is deficient in available bases, particularly calcium, and which gives an acid reaction when tested by standard methods.

There is no full agreement on the most satisfactory test for ''acidity'' and field tests are made by the use of various convenient indicators. The intensity or degree of acidity can be expressed by the qualifying words—strongly, moderately, etc.

Alkali Soil—Alkali: A soil containing any soluable salts in sufficient amount to cause injury to economic plants.

Alkaline Soil: A soil containing an excessive amount of the alkaline (in true chemical sense) salts, usually sodium carbonate.

Saline Soil: A soil containing excessive amounts of the neutral or non-alkaline salts, usually chlorides and sulphates.

In reprinting the glossary presented by Mr. Shaw, we have omitted many of the terms that we believed would be of little interest to 90 per cent of our *Record* readers.

Attention is called to the "Introduction," wherein the author states that most of the terms apply to soil in the field. For example, clays are listed with the group terms that are differentiated by their physical characteristics without reference to their chemical composition. Hence the term finds a wide and correct local usage in Hawaii, which would not be true if the definition were to be applied only to the true clays, the hydrated aluminum silicates, for these silicates are not found in Hawaiian soils.

In regard to the terms listed under "chemical characteristics," we feel that the local usage of "acid" and "alkaline" soils, with their various intensities as determined by the pH analyses, are desirable. Thus *for the agricultural soils* in Hawaii, we would justify the terms that follow:

Very acid	Below pH 5.2	Very alkaline.......	Above pH 8.8
Acid	pH 5.2—pH 5.7	Alkaline	pH 8.3—pH 8.8
Moderately acid.....	pH 5.8—pH 6.3	Moderately alkaline.	pH 7.7—pH 8.2
Slightly acid.......	pH 6.4—pH 6.7	Slightly alkaline....	pH 7.3—pH 7.6
Neutral	pH 6.8—pH 7.2		

In the original paper, the author makes the following comment concerning his "chemical terms":

A few chemical terms in general use are included in the glossary. It is hoped that the term "Alkali Soil" can be eliminated and these soils more correctly designated as Alkaline or Saline soils, depending on the character of the compounds present. If it is felt necessary to have a general term to express the opposite of "Acid" soil, the term "Basic" soil might be better.

R. J. B.

Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
DECEMBER 28, 1933, TO MARCH 15, 1934

Date	Per Pound	Per Ton	Remarks
Dec. 28, 1933	3.15¢	$63.00	Philippines.
" 29	3.175	63.50	Philippines, 3.15; Cubas, 3.20.
Jan. 2, 1934	3.20	64.00	Cubas.
" 11	3.165	63.30	Philippines, 3.16; Puerto Ricos, 3.17.
" 17	3.17	63.40	Puerto Ricos, Philippines.
" 19	3.20	64.00	Puerto Ricos.
" 26	3.23	64.60	Puerto Ricos.
" 27	3.24	64.80	Puerto Ricos, 3.23, 3.25.
" 31	3.25	65.00	Puerto Ricos.
Feb. 3	3.30	66.00	Puerto Ricos.
" 5	3.35	67.00	Puerto Ricos.
" 7	3.39	67.80	Puerto Ricos.
" 8	3.4733	69.47	Puerto Ricos, 3.40; Philippines, 3.42; Cubas, 3.60.
" 13	3.3767	67.53	Puerto Ricos, 3.35, 3.38, 3.40.
" 14	3.35	67.00	Puerto Ricos.
" 15	3.46	69.20	Cubas, 3.57; Puerto Ricos, 3.35.
" 16	3.45	69.00	Puerto Ricos, 3.35; Cubas, 3.55.
" 17	3.33	66.60	Puerto Ricos.
" 19	3.30	66.00	Puerto Ricos, Philippines.
" 20	3.27	65.40	Puerto Ricos.
" 21	3.29	65.80	Philippines.
" 26	3.385	67.70	Puerto Ricos, Philippines, 3.30; Cubas, 3.47.
" 27	3.30	66.00	Puerto Ricos.
" 28	3.31	66.20	Philippines, 3.30; Puerto Ricos, 3.32.
Mar. 1	3.32	66.40	Puerto Ricos, 3.34, 3.32; Philippines, 3.30.
" 2	3.30	66.00	Philippines.
" 5	3.26	65.20	Puerto Ricos, 3.27, 3.26, 3.25.
" 6	3.215	64.30	Puerto Ricos, 3.23, 3.20.
" 7	3.20	64.00	Puerto Ricos.
" 12	3.34	66.80	Cubas, 3.48; Puerto Ricos, 3.20.
" 13	3.17	63.40	Philippines, 3.19; Puerto Ricos, 3.15.
" 14	3.15	63.00	Puerto Ricos.
" 15	3.42	68.40	Cubas.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVIII THIRD QUARTER, 1934 No. 3

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

Charles F. Eckart

Charles F. Eckart died in California on June 20, 1934. The part that he took in the development of scientific agriculture in Hawaii was an important one, and he may be looked upon as one of the pioneer workers in the application of science to sugar production in these Islands.

A chemist by profession, he came here first in 1895 in the employ of the Paauhau Sugar Plantation Company. It was in that year that the Experiment Station of the Hawaiian Sugar Planters' Association was started under the direction of Walter Maxwell. A year later Mr. Eckart became associated with Dr. Maxwell in the work of the Station. When Dr. Maxwell left the Islands for Australia in 1900 he was succeeded for a brief time by R. E. Blouin, and when Mr. Blouin returned to Louisiana in 1901, Mr. Eckart became director of the Station.

With the development of new branches of work in 1904-1905 he participated in the direction of the enlarged activities (as director of the Division of Agriculture and Chemistry) with Dr. R. C. L. Perkins (director of the Division of Entomology) and Dr. N. A. Cobb (director of the Division of Pathology and Plant Physiology). In 1909 when the three divisions were combined as a single institution, Mr. Eckart became director of the reorganized station, and continued in that office until June, 1913, when he resigned to become manager of the Olaa Sugar Company, Ltd. In 1920 he became a director of that company and participated in its management in a consulting capacity for several years. He moved to California in 1926.

During the early years of his connection with the Experiment Station his work included fundamental studies of Hawaiian soils, and the problems of tolerance of sugar cane to saline irrigation waters. The important question of cane varieties later received his attention, and following the work of Soltwedel in Java, and that of Harrison and Bovell in Barbados, he and his associates undertook the propagation of seedling varieties of sugar cane in Hawaii.

In 1905 a group of 5,000 seedlings was germinated and as these attained maturity in 1907 thirteen were marked by Mr. Eckart as particularly promising

canes. One of these, given the number "H-109," was a few years later adopted and spread rapidly at Ewa by the late George F. Renton, and afterwards by all the irrigated plantations of Hawaii, attaining finally an area of over 100,000 acres, and contributing greatly to the large crops of sugar produced in Hawaii in recent years.

At Olaa, Mr. Eckart developed some interesting and novel agricultural practices. He was the first to make practical application of a chemical herbicide between the rows of a cultivated crop, and he was the inventor of a system of paper mulching, used originally in cane fields, and since widely employed in pineapple culture.

Mr. Eckart was born in Marysville, California, June 18, 1875. He was a graduate of the University of California, and also held a post-graduate degree from that institution. He will be remembered and honored for the constructive work that he did for the betterment of agriculture.

In This Issue:

The Regional Variety Stations in the Seedling Selection Program:

The harvesting results from the Field Test 2 plantings on the regional stations are summarized. The different parentage groups and types which have shown to best advantage in each station are discussed; and the procedure followed in choosing seedlings in these tests for plantation trial is outlined.

Introduced Tropical American Toad:

This beneficial amphibian has found Hawaiian conditions suitable as a new habitat and is now definitely established and multiplying rapidly. Its life history and food habits, as observed in Hawaii, are given together with a discussion of its general behavior, methods of rearing, growth and local distribution to date.

Water and Cane Ripening:

This paper reports the results of a preliminary study to determine the effect of withholding water upon the formation and storage of sugar in cane. It represents an attack upon the important problem of the effect of water upon cane ripening, made from the physiological point of view.

The results show that the manufacture of sugar occurs in cane at the wilting point, but at a reduced rate. Whether the increase in the formation of sugar which occurs in the plants receiving an adequate amount of water is enough to offset the loss due to their increased growth, remains to be determined in the next experiment.

The Basic Reasons for Phosphate Fixation:

In previous articles phosphate fixation has been discussed in a general way, and also with respect to the variation in the fixing powers of different soils. Phosphate fixation is here treated from the standpoint of determining what causes soils to fix

phosphates, and what actually takes place in a soil when phosphates are fixed and held by it.

The phenomenon of fixation is not alone one of simple chemical precipitation, or merely that of adsorption (the property by which one substance can attract and hold another substance as bone char adsorbs the coloring matter of a sugar solution). The study indicates that *absorption* plays a prominent part, that is, the property by which two substances become intermingled in a state known as the "solid solution". We have examples in metallic alloys.

The phosphate-fixation property of a soil relates to its colloidal structure. A colloidal state may exist by reason of great fineness of division of a substance, but colloids may also take the form and complex structure of a gel. It is within the gel-like structure of certain soils that phosphates are thought to be fixed by a process of absorption and held in a state difficultly available to plants.

Fixation of phosphates may be thought of as due to a combination of simple chemical precipitation, adsorption and absorption.

For Better Field Experiments with Fertilizers:

A series of plans for fertilization and arrangements of treatments is offered as examples that may be used by plantation agriculturists who desire to install high-grade field experiments concerned with fertilizer problems and related issues.

A Required Standard for "Grade A" Experiments:

At a meeting of plantation men held at Hilo early in 1931, it was the consensus of opinion that continued emphasis should be placed on well-planned, well-replicated, carefully executed field experiments, the results of which could be considered reliable; and it was proposed that such experiments meeting this standard would be officially termed "Grade A" experiments.

Following several years of study and consideration of the many factors which make for a high standard of excellence in field experiments, we have adopted a set of minimum standards for those experiments which the Experiment Station is to recognize as "Grade A."

Potash Occurring in Irrigation Water in Relation to Plant Fertilization:

This paper describes in detail a study made upon fields in two locations on Central Maui, where the irrigation used consists of pump water which carries comparatively high concentrations of potash.

Researches are described bearing upon the functions of this potash as a plant nutrient for sugar cane. Data are set forth and discussions ensue which lead to the conclusion that the potash in the irrigation water has actually contributed to the fertilization of cane, and in one case is apparently responsible for a luxury consumption of the nutrient by the crop. References are made to other studies bearing upon the subject. Comparisons are also included of analytical procedures used in the course of the investigation.

The Regional Variety Stations in the Seedling Selection Program

By C. G. Lennox

In 1930 the first plans were laid for the establishment of seedling testing stations in locations which would be typical of the different large areas of land under sugar cane cultivation. Some of the fields at the Waipio Substation were being used in preliminary selection work with the new seedlings, and while it was recognized that the growth conditions there were suitable for testing for irrigated conditions, in general, they were not typical of many of the cane areas in the Islands. A deliberate attempt to select representative locations resulted in the establishment, in 1930, of testing fields at Hilo Sugar Company as being typical of the so-called Caledonia belt on the Hilo Coast, and in the middle irrigated "eye spot" belt at Lihue Plantation Company, Ltd., on Kauai. The following year sites were chosen as representative of the middle belt on the Hamakua Coast and of the mauka lands on the Hilo Coast. These areas were augmented the following year by one in the middle belt of the Kohala District and one at the highest elevation at which cane is grown in the Hamakua District.

The purpose of the regional station plan is twofold. First, it relieves the plantations of the expensive and difficult task of testing many relatively untried seedlings. Second, it strengthens the whole seedling testing program by offering an opportunity to observe the behavior of the new canes under a wide variety of conditions as well as offering a plan for their careful testing in each district for a period of 3 to 6 years before they are released to the plantations.

During the harvesting season of 1934 a full cycle of testing has been completed at all the regional stations except Kohala. The seedlings which have completed this cycle have passed through the following stages:

(1) Field Trial 1 in which only eight feet of line is planted to each seedling and the final selection is made at the end of one year. Selection is based primarily upon agricultural qualities and apparent weight of cane as compared with the check variety. A Brix reading will eliminate the canes exceptionally low in sucrose content.

(2) Field Trial 2 in which a plot of three lines 15 feet long is planted to each seedling and the final selection is made at the end of 20 to 24 months. Check plots of the standard variety are planted adjoining each seedling. Selection is based upon the yield of sugar per acre as compared with the standard variety and the appearance of the cane on the ground at harvest.

The few seedlings which are chosen for plantation distribution are those which have outyielded the check by a good margin and the general records of which for sucrose content, disease resistance and agricultural qualities are all satisfactory.

It will be of interest to examine the results of this first completed cycle of testing at each regional station.

A Field Trial 2 planting in which a plot of three 15-foot lines are planted to each seedling and the final selection is made at the end of 20 to 24 months. The distribution charts which follow in this article show the tons-sugar-per-acre gain or loss of the seedlings in these tests over the standard cane at each variety station.

Waipio Variety Station

The preliminary testing of seedlings was started at Waipio two years before those at the other regional stations so information is therefore available on the ratoons of Field Trial 2. The distribution chart shown in Fig. 1 gives a general idea of how the seedlings under trial compare with H 109 on the whole. The population represents a wide assortment of parentages ranging from Uba seedlings through the medium-stalked type produced by P.O.J. 2364 to the large-stalked seedlings of Yellow Caledonia. The majority are of the series propagated in 1928.

The plant crop was 22 to 24 months old at harvest and shows a total of 95 seedlings outyielding H 109. The canes in this group represented a fair cross-section of all the parentages in the population although the P.O.J. 2364 group predominated. The first ratoons were harvested as a short crop. The value of P.O.J. 2364 blood for short cropping purposes is clearly demonstrated here for it is found dominating the group of high yielders.

Fig. 2 shows the distribution of the tons-sugar-per-acre gain and loss over H 109 of a population of 605 seedlings harvested for the first time in 1934. The relative high standard of this new group, as witnessed by the fact that more than half the number outyielded H 109, might be attributed to the following:

(1) A more rigid selection from the F.T. 1 planting due to a larger number of seedlings from which to select.

(2) A wider range of parentages to work with due to the fact that newly

introduced breeding canes had been employed in making many of these crosses. (Seedlings of the 1927, 1928, 1929, 1930, and 1931 series were represented in this population.)

(3) A knowledge from past experience as to which types and parentages succeed under these conditions.

The question naturally arises as to how such an unwieldy number of seedlings can be reduced to a number of convenient size to work with on plantations. This is accomplished by submitting each individual to a critical examination which in brief is as follows:

(a) Seedlings which show a gain of from one to two tons of sugar per acre only over the check are eliminated unless their other records are well above the average. This eliminates those which have possibly made their gain through chance experimental errors.

(b) A careful examination of the cut cane reveals the individuals with excessive dead cane, borer or rat damage, and trashiness. These qualities which comprise "condition of cane at harvest" play a large part in reducing the number.

(c) The greatest elimination comes when the records of each individual are referred to and a general idea is obtained on its performance in a number of other plantings. These data tell us whether the high yields obtained in the experiment were to be expected or are possibly "fluke" gains and may not happen again. The factors looked for when examining the records are: average juice quality, ratooning ability, shading-in characteristics, tasseling tendencies, ability to *lala,* and tolerance of the diseases found in the various districts.

The process of weighing all the qualities of one cane against those of another gradually reduces the number to a comparatively small group. Within the group remaining there are all degrees of confidence in the seedlings represented. Those in which we have the greatest confidence are the ones on which the greatest number of favorable observations from different plantings are available.

The seedlings which have not quite measured up to a standard high enough to include in the group for plantation distribution are not discarded but are given additional trials in Field Trial 2.

In following the procedure of elimination described we find it is possible to reduce the 350 seedlings which outyielded H 109 at harvest, as illustrated in Fig. 2, to a group of only 30. Even this number is not suitable in its entirety for all irrigated conditions because some are too susceptible to eye spot disease. It is interesting to note that the wide range of parentages, represented in the original population of 605 seedlings, is not found so distributed among the 30 leaders; for here 17 are hybrids of P.O.J. 2364, 3 of Yellow Caledonia, 3 of P.O.J. 2878, and 7 of miscellaneous parents.

Hilo Variety Station

It has often been pointed out that Yellow Caledonia is a difficult variety to replace for the conditions existing on the Hilo Coast. This is well substantiated by the fact that relatively few seedlings outyielded Yellow Caledonia at the Hilo Station as compared with the larger proportion which did so at the Waipio, Kauai, and Hamakua stations.

It will be noted in Fig. 3 that 43 seedlings bettered Yellow Caledonia in tons sugar per acre by a wide range of gains. A study of this group reveals that more than one-third of this number were P.O.J. 2364 hybrids, with the Uba x H 456 seedlings next in prominence. After the whole number had passed through the scrutinizing process we find 8 remaining as suitable for distribution. P.O.J. 2364 blood still dominates this group to nearly a complete exclusion of all others.

The selection of seedlings for the conditions found on mauka lands of the Hilo Coast is conducted in a field located at an elevation of approximately 950 feet. The standard variety used is P.O.J. 36, which has replaced D 1135 in these parts within recent years. Fig. 4 shows the distribution of the T.S.P.A. gains or losses of the 51 seedlings in the "Field Trial 2" tests harvested at this location in 1934. A total of 15 outyielded P.O.J. 36. They are all seedlings of Uba x H 456 except Co. 281 and Co. 290. The factor of "susceptibility to leaf scald disease" plays a large part in reducing the number suitable for plantation distribution to only five.

Hamakua Variety Station

A rather wide range of parentages are adaptable to the conditions found in the middle belt of the Hamakua District. In the population of 43 (see Fig. 5) which was harvested this year as 21-month old cane, we find the 32 seedlings which outyielded the standard (P.O.J. 36) in sugar to be from crosses of Uba x H 456, P.O.J. 2725 and P.O.J. 2364 x Yellow Caledonia seedlings, and a few from miscellaneous small-stalked parents. The largest proportion, however, are of the first-named parentage, which indeed distinguished itself by having all of its seedlings in the total number tested outyield P.O.J. 36.

After the process of examining all qualities of each seedling was complete a total of 11 remained as material good enough for plantation distribution. Uba x H 456 dominates this select group, with all the P.O.J. 2725 and P.O.J. 2364 seedlings eliminated, excepting 28-1234. In addition to these, three seedlings of miscellaneous parents remain.

Kauai Variety Station

The element of eye spot resistance in a new seedling is of primary importance in the selection for F.T. 2 testing at the Kauai Variety Station. The result is that many canes which may be outstanding in agricultural qualities must be eliminated because of susceptibility to this serious disease. A total of 104 eye spot-resistant seedlings were harvested as 21-month old cane, and as Fig. 6 shows, there were 33 which showed gains in sugar over P.O.J. 36. This number was reduced to 9 when eliminations were made for small-stalk canes, poor juice records and other features. A rather wide range of parentages is represented in these few.

Summary

In the foregoing discussion an attempt has been made to point out the different parentage groups as well as different types which have shown to their best advantage under the climatic and cultural conditions existing at each station. The annual accumulation of information of this nature adds to the knowledge of which

type and which general parentage groups will give the most satisfactory results at each place. They also aid in determining the broad lines of breeding policy to be followed. The choice of the few outstanding individuals for distribution to plantations is strengthened, (1) by virtue of a trial conducted under the general field conditions for which they are intended, and (2) by the added surety given by observations from different plantings.

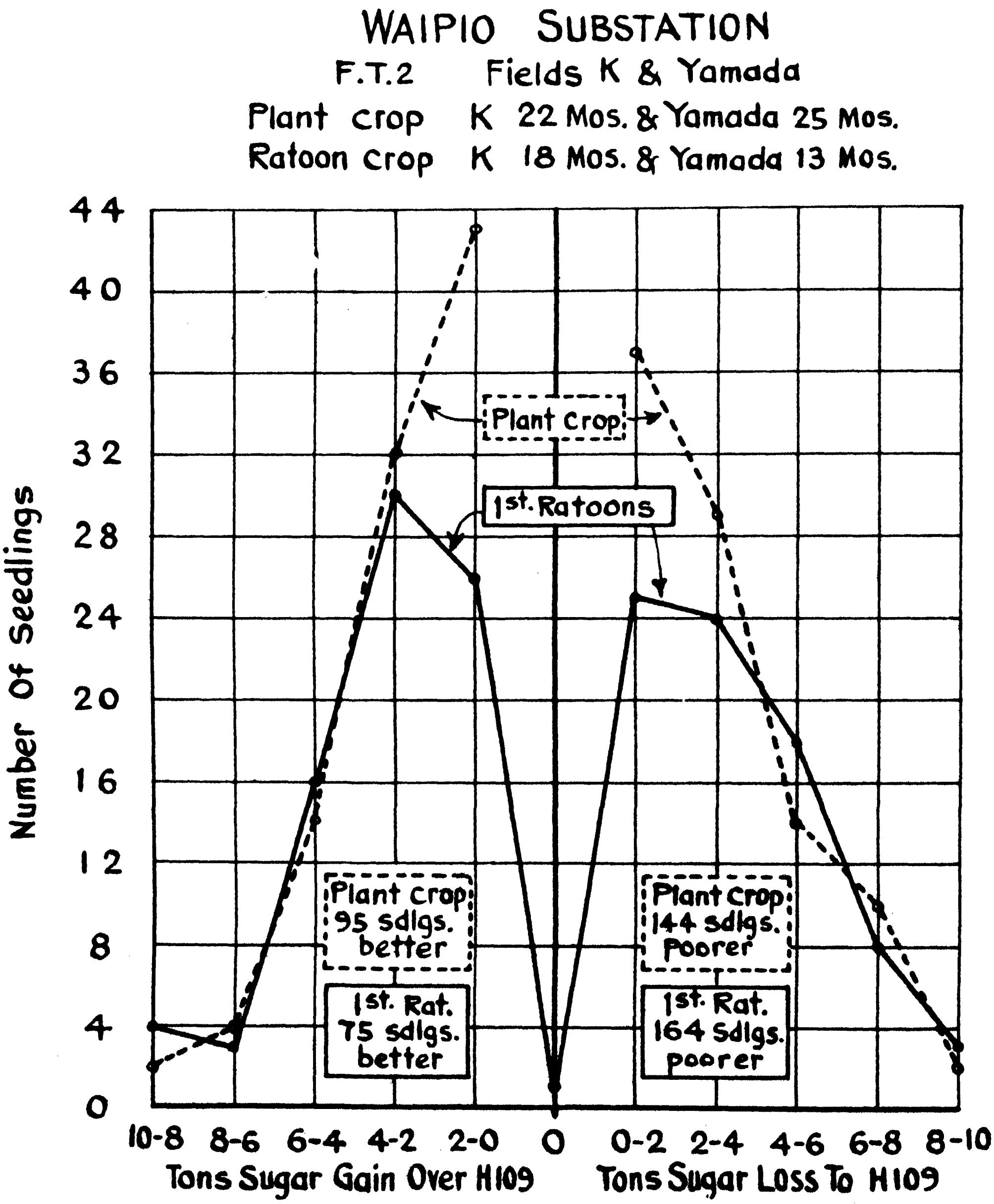


Fig. 1. Seedlings of P.O.J. 2364 are among the highest yielding canes in both the plant and ratoon crops represented above.

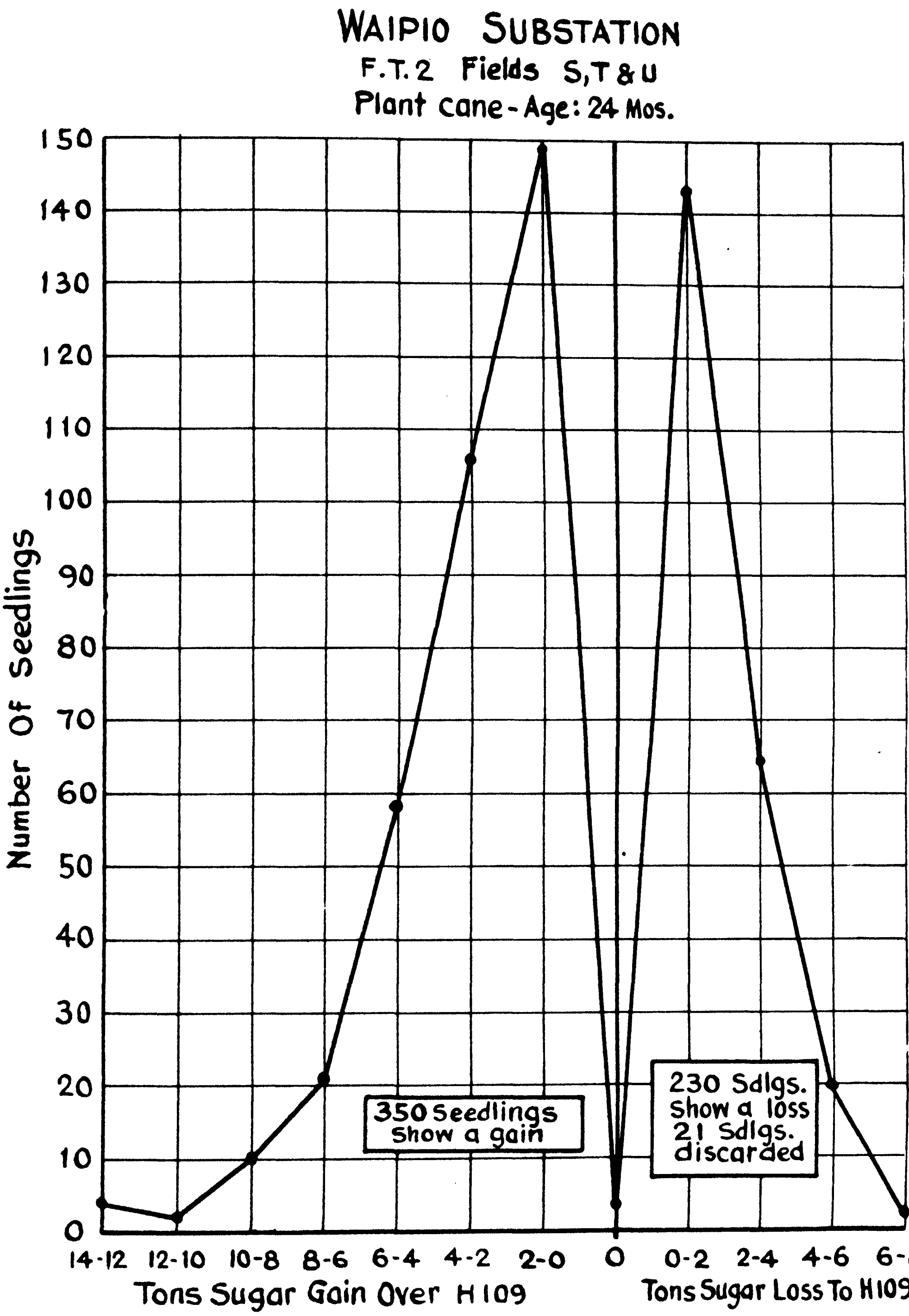


Fig. 2. When the records of the 350 seedlings which outyielded H 109 are carefully scrutinized it is found possible to reduce this number to a group of 30 seedlings suitable for recommending to plantations for trial under H 109 conditions.

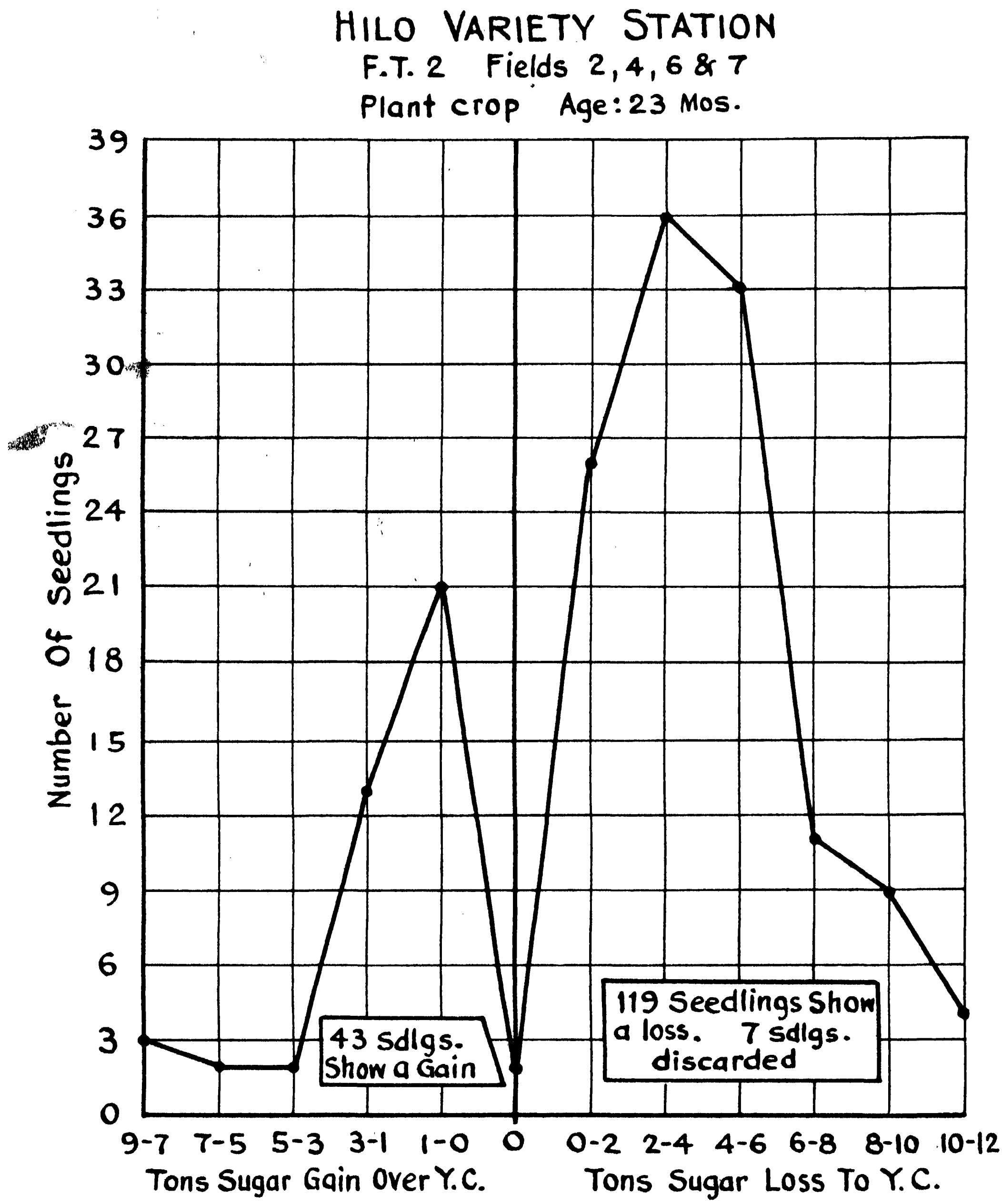


Fig. 3. The strong position held by Yellow Caledonia on the Hilo Coast is well illustrated by the relatively small percentage of seedlings which bettered it.

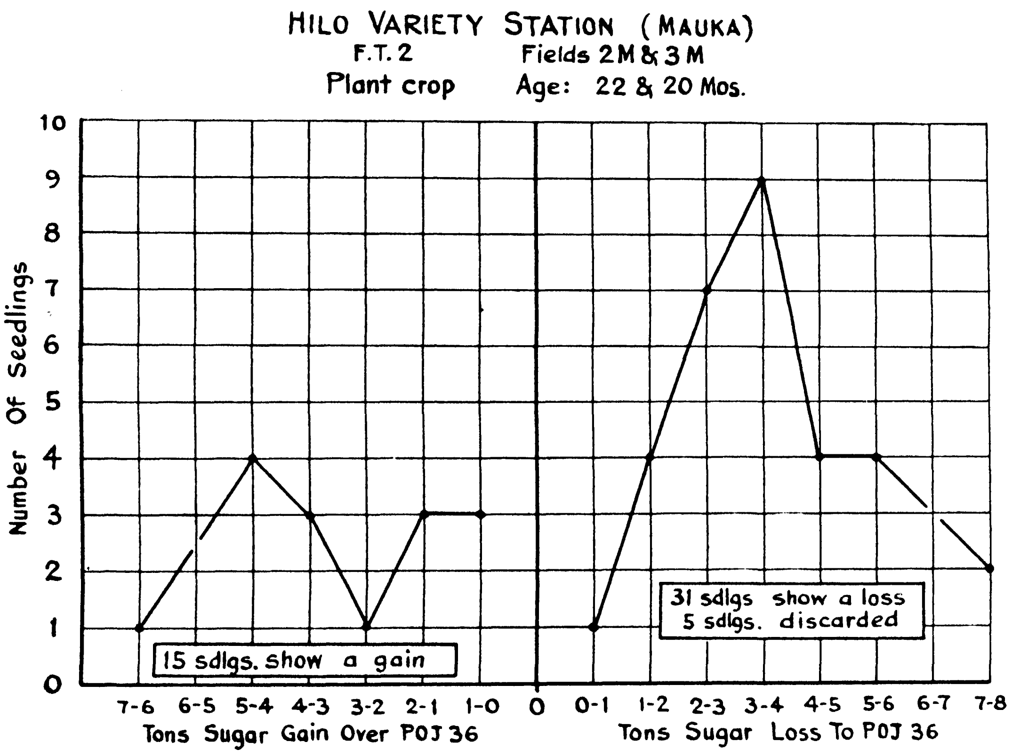


Fig. 4. Co. 290, Co. 281 and three seedlings of Uba x H 456 are the few in this population which are considered worthy of further trial under these conditions.

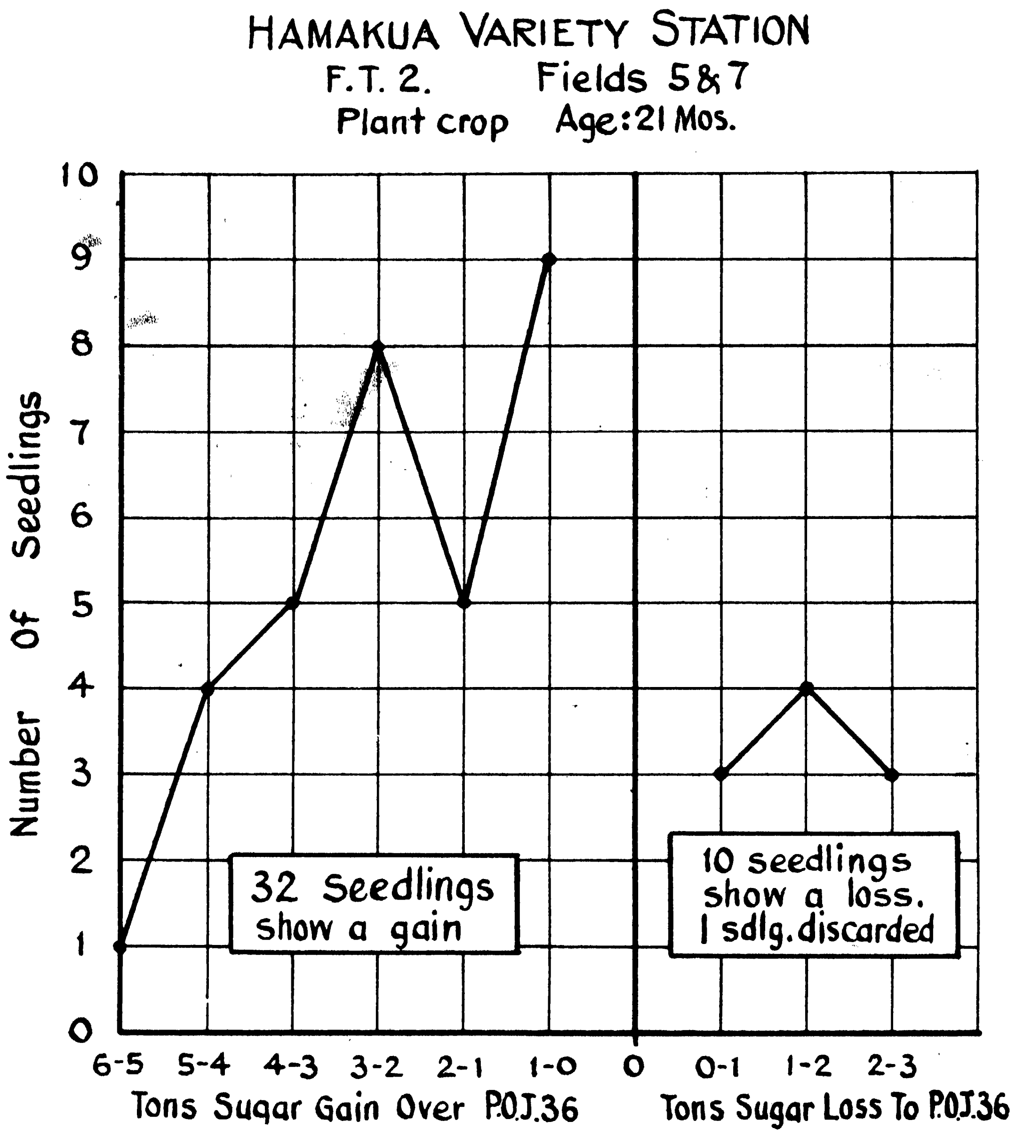


Fig. 5. The distribution curve shown above would indicate that P.O.J. 36 is a weak competitor against nearly all the new seedlings in the test. The factors of economy of weed control and rapidity of ratooning play a large part in reducing the number which are suitable for trial on plantations from 32 to 11.

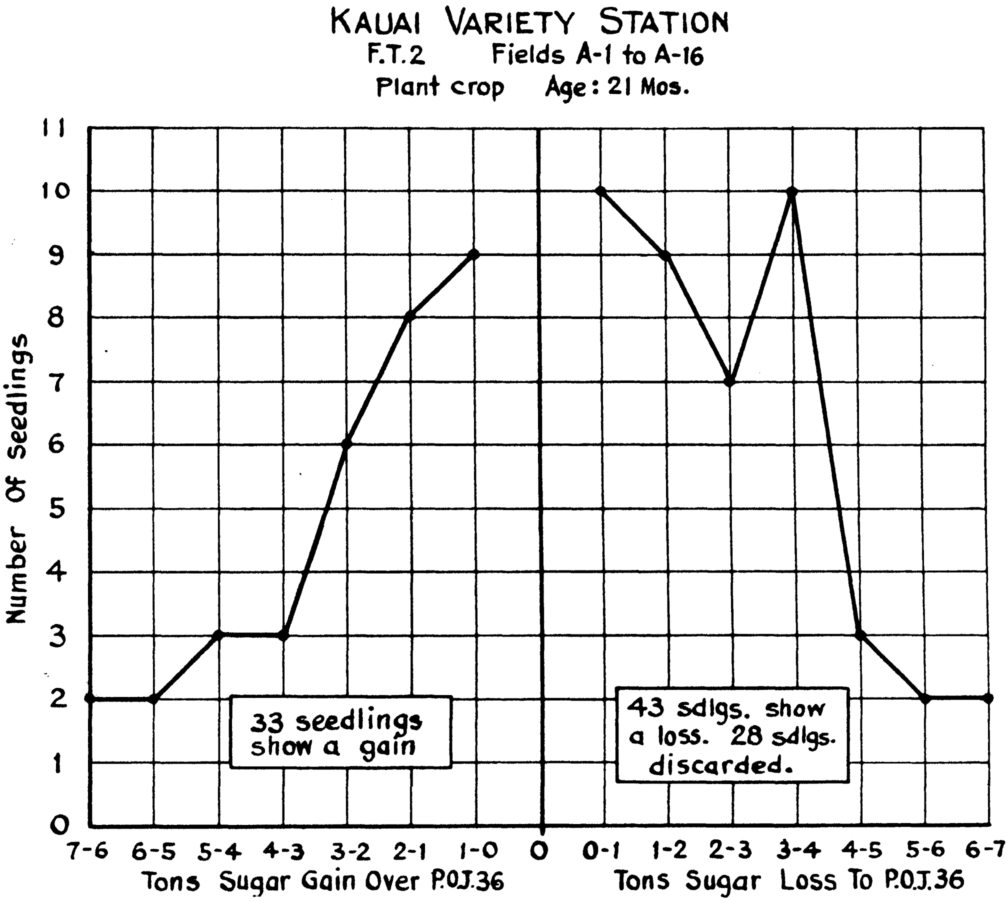


Fig. 6. All the seedlings in the population are commercially resistant to eye spot disease. After an examination of the records 9 can be chosen as worth further trial.

Local Investigations on the Introduced Tropical American Toad *Bufo Marinus*

By C. E. PEMBERTON

The introduced giant tropical American Toad *Bufo marinus* (Linné) has now added one more item to its interesting history, for it is definitely established in the Pacific Region for the first time and is multiplying rapidly on Oahu. This, the largest of the true toads, was first described and figured by A. Seba in 1734. The specimen examined by Seba was part of a collection bought for 15,000 Dutch guilders by "Peter the Great" of Russia in 1716 and deposited in St. Petersburg. This collection became part of the St. Petersburg Academy of Sciences, established by Catherine I, December 21, 1725.* Linnaeus named the toad *Rana marina* in 1758. With its establishment in the Hawaiian Islands, importation to other parts of the Pacific will naturally follow. Already a small consignment has been taken from Honolulu to the Philippine Islands.

In a little over two years the 148 toads which were introduced into Hawaii from Puerto Rico, have increased their number to many thousands. This rapid development has resulted entirely from the original field liberation of 80 in a taro patch bordering a rice field at Waipio, Oahu, and 68 in some swampy land in the Manoa Arboretum at the head of Manoa Valley, Honolulu. These liberations were made during April, 1932. All were good-sized toads. Young toads were first seen at Waipio, August 31, 1932, and in Manoa Valley, March 7, 1933. Only a few were found but this gave proof that eggs had been laid and that the species would probably become established. By May, 1933, quite a number of half-grown Hawaiian-born individuals were seen in upper Manoa Valley, and in August of the same year many young toads were found in a rice field at Waipio. It was also comparatively easy to find, in the same locality, some that were of fairly good size. It seemed quite probable that Hawaiian-born toads of this species had started egg-laying by September, 1933, for many young toads began appearing in several parts of Waipio and even in the Waipio reservoir, which is well-removed from the spot where the original liberation was made. The sudden appearance of young toads in fair quantity in upper Manoa Valley further substantiated this belief.

The toad has spread slowly down Manoa Valley from the point of original liberation. It now abundantly occupies the taro patches of the valley and is frequently seen in the residential gardens, especially on the western side.

Commencing in May, 1933, a few distributions were made from Manoa Valley and Waipio to other localities on Oahu. During the latter half of 1933, the species rapidly gained headway and distributions were increased. By the end of the year, 947 had been moved to many places on Oahu and some had been sent to other islands. During the first half of 1934, thousands were obtainable at Waipio and

* **Mexican Tailless Amphibians in The United States National Museum. By Remington Kellogg. Bulletin 160, United States National Museum, Smithsonian Institution, Washington, D. C., 1932, pp. 53-57.**

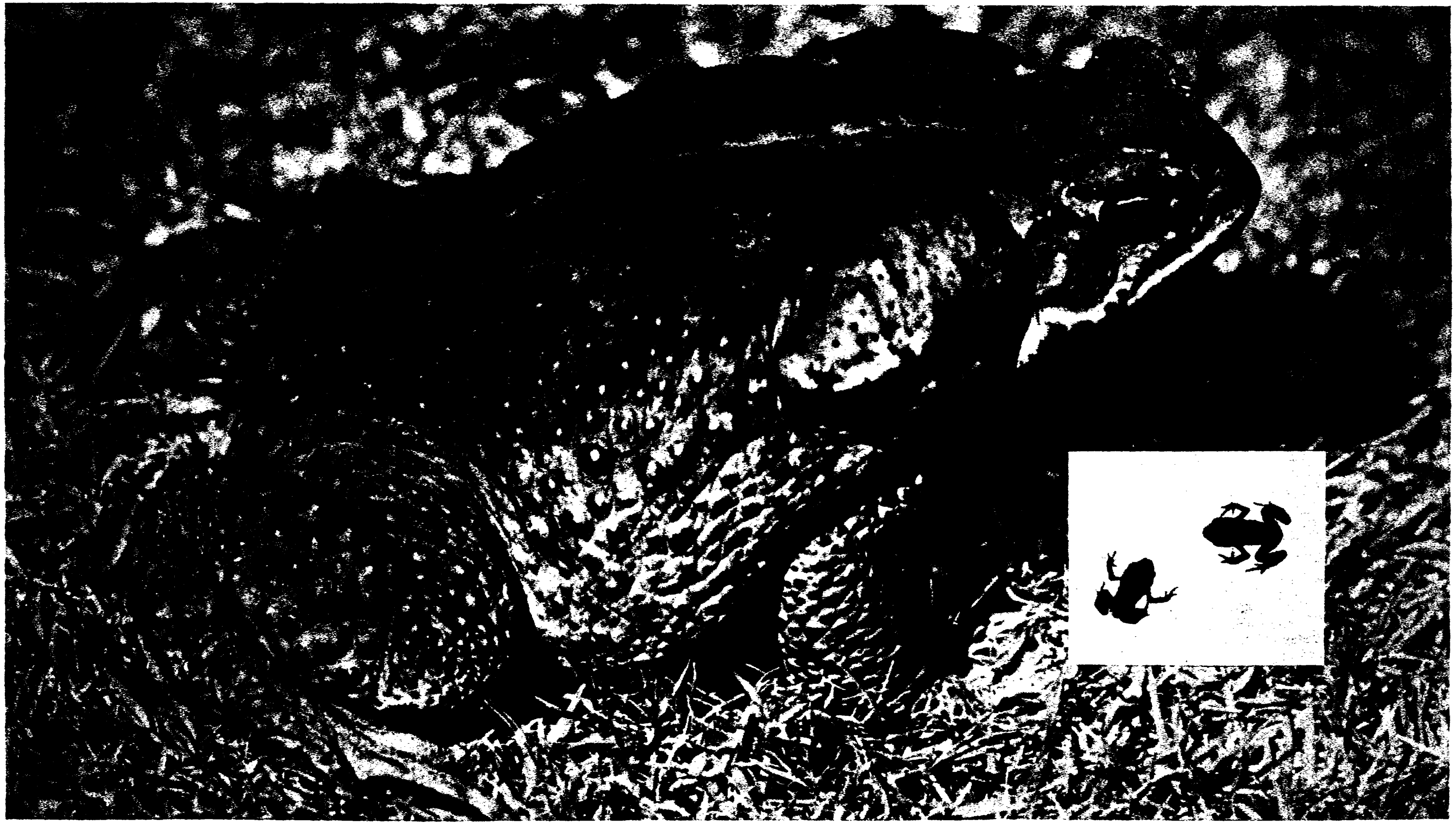


Fig. 1. *Bufo marinus.* Adult 16½ months old. Insert. The same 3 days old. *All natural size.* The young toads weighed approximately 1/10 of a gram each, whereas the adult tipped the scales at 491 grams. This increase in weight, by nearly five thousand times in 16½ months has resulted from the consumption of from 1500 to 2000 insects.

distributions have been made to every plantation in the Territory. At the present writing (July 23, 1934), a total of 103,517 has been distributed. Most of these toads have been placed within Anomala-infested portions of Oahu Sugar Company, Ltd., where this insect is the most abundant. Fair numbers have also been liberated in Anomala-occupied fields of Honolulu Plantation Company and Ewa Plantation Company. Almost all of the distributed toads came from Waipio.

Most of the toads so far distributed have been young individuals. From present evidence, it seems certain that they are not sexually mature until about a year old. The large number of immature toads distributed to date cannot be expected to begin multiplying until the summer of 1935. The saturation point for this toad in Hawaii will not be reached for several years; but within one or two years from the present date it will probably be sufficiently numerous to be familiar to almost every resident in the Territory, if the increase to date from the few introduced individuals can be accepted as an index.

The large distribution accomplished during the past few months, has been made possible through the enterprise of F. C. Denison at the Waipio Substation of the Experiment Station and certain members of the staff under his direction, notably L. M. Shigeura. Toad eggs are collected from the rice field adjoining the Waipio Substation and held in large pans of water until they hatch. The tadpoles are then placed in large pans of water set into the ground in pens several yards square in which grass and weeds are growing. The pens are partially shaded by overhanging branches of mango trees. Running water circulates continuously through the pans. Though tadpoles normally feed upon green algae and other minute aquatic plant life, Mr. Denison found, after experiment, that poi, boiled rice, cooked Cream of Wheat and Carnation Flakes were greedily eaten by the tadpoles and that they developed to the toad stage quicker if given such artificial food in place of the green algae. By such a method of feeding he determined that the Bufo tadpoles became fully developed and changed into young toads in about 25 days. With normal food, such as they obtain under natural conditions, we find that the tadpole stage occupies about 30 days. Eggs hatch within a few days after being deposited. Some kept under observation during May, 1933, began hatching 2 days and 20 hours after being laid. The newly hatched tadpoles are 1/5 of an inch long and absolutely black. When full grown they are less than an inch long. A pair of hind legs is plainly discernible when the tadpole is about half grown and a few days before it matures to a toad the front pair of legs also appears.

As soon as the tadpole stage is ended, the aquatic life of the immature Bufo is abruptly given up and the young toad, hardly more than ¼ of an inch long, climbs ashore and begins foraging for ants and minute insect life among the weeds and grass close to the water from whence it has emerged. They prefer to remain where the ground is cool and moist and will readily plunge back into the water if disturbed. Quantities of ants are placed daily in the cages at Waipio to supply the first food for the young toads as they change from tadpoles in the pans of water and come ashore. Within a few days they are ready for distribution and will stand shipment very well through the mails to the other islands, if packed loosely in moist excelsior in any container which will not be crushed. The cages can be kept heavily stocked with young toads through the collection of only a few Bufo egg-masses per month. The eggs are laid in curling rows or strings several

feet in length. They are jet black and imbedded in a mass of gelatin-like substance. By counting the number of eggs within a given length of a part of one egg-mass, it was estimated that the total number of eggs per mass amounted to at least 10,000.

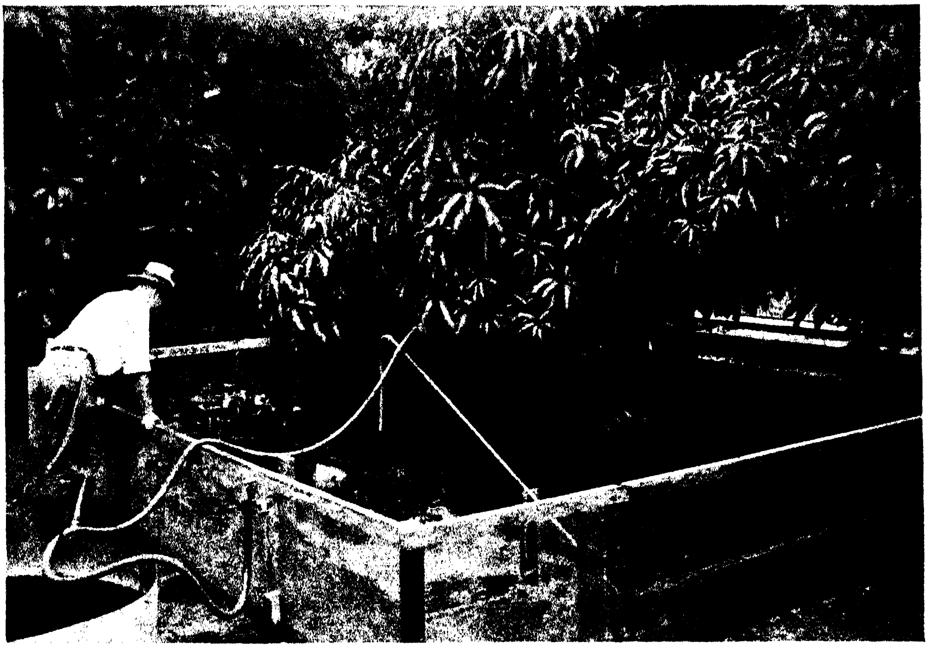


Fig. 2. Toad hatchery at Waipio.

It is not known how many times a year a toad may deposit eggs, but egg-masses have been found in the field at Waipio almost every month of the year. During 1933, our first year of study, no eggs were found during the summer months; however, during July, 1934, after the toads had become very numerous in the rice field at Waipio, eggs were found and it is quite probable that they will appear from now on during every month of the year.

As already stated, the newly developed toad is hardly over a quarter of an inch long. Some have been measured which averaged about 2/5 of an inch from the front of the head to the tip of the stubby tail. This tail is soon absorbed. After a week or more of feeding on ants and other very small insects, the toad gains rapidly in strength and agility and may attempt an insect barely small enough to pass into its mouth and down its throat. Growth is rapid and they seem exceptionally able to find and capture all the insect food they require. Toads in our cages that were three months old, varied from 2½ to 3 inches in length and would even swallow mature Chinese grasshoppers *Oxya chinensis;* but only after considerable effort and by assistance with their hands or front feet. Twenty-five toads, which have been reared in a cage and fed all the insects they required, varied in size from 3½ to 4⅝ inches in length at the end of 6 months. F. X. Williams placed two young toads in a cage during February, 1933, to observe their growth and habits. These were 2/5 and 3/4 of an inch in length, respectively, at that time. They have been fed about all they could eat up to the present date (July 23, 1934). One is now over 6 inches in length and more than 4 inches

in width at the widest part. In order to attain such a growth in 16½ months, an individual toad undoubtedly consumes from 1500 to 2000 insects of various sorts.

From our local observations it is apparent that *Bufo marinus* will eat any insect that comes within its reach, large or small, providing the toad has grown sufficiently to enable the victim to pass down its throat. We have fed them grasshoppers, armyworms, beetles, earthworms, scorpions, wasps, moths, bees, house lizards or geckos, ants, many sorts of caterpillars, snails in the shell, cockroaches and sow bugs or slaters; all of which were taken with little discrimination. The geckos are usually too quick and secretive to be caught without our assistance. If these tender reptiles are held before a toad, they are quickly grasped and swallowed, apparently to the great satisfaction of Bufo. A toad about 4 inches in length was given a male carpenter bee *Xylocopa varipuncta,* with the wings trimmed to prevent its escape; this was swallowed without hesitation. A female bee of the same species was later given to the same toad and was also immediately snapped up and passed down the insatiable Bufo gullet with ease. This large black carpenter bee, so commonly found boring in redwood fence posts and other wood structures in Hawaii, possesses an exceedingly powerful sting which is used effectively at the slightest provocation. Undoubtedly the bee will continue stinging for a few moments, at least, after passing suddenly into the interior of a toad. It is astonishing that a toad will, without hesitation, gulp down a bee possessing such a formidable weapon of defense and apparently suffer no discomfort. After swallowing such a fiery creature as a carpenter bee, Bufo was observed to execute a few abdominal motions suggestive of the Hawaiian "hula dance". Spiders are always eaten with relish if they come within reach of the lightning-like flash of the toad's tongue. Dr. Williams found that freshly decapitated centipedes, which are still able to crawl, are eaten apparently without fear of injury; but the many legs of large centipedes are usually able to cling over the mouth or head of the toad so tightly that the process of swallowing such a long object is often accomplished only after much laborious gulping and pushing and pawing with the front feet in a very human but "inelegant" manner, according to Dr. Williams' notes. A half grown toad was given a very large and uninjured centipede, measuring at least 6 inches in length. This was almost immediately grasped in the mouth and several attempts were made to swallow it. In this case, however, the powerful muscles and smooth skin of the centipede, assisted by its many, strong, claw-tipped legs, enabled it to successfully escape. Good-sized toads will easily capture and swallow centipedes four inches in length.

Toads consume scorpions without difficulty. The largest scorpions we have been able to find in Honolulu are readily swallowed by toads less than half grown.

Usually when given more insects than can be consumed within a short period, Bufo will cease feeding but only after its body has become visibly engorged.

Toads will feed at any time of the day or night, but are most active after sunset. They are known to visit certain spots where food is obtainable at regular intervals, once such spots are located. In Puerto Rico, shrubs on which certain defoliating beetles accumulate in the evening, are known to be regularly visited at night by this toad for the evening feast, after which it returns to some safe retreat to spend the day. The possession of such an instinct or memory usually results beneficially to man, but in one case, at least, the reverse was true. Mr.

Denison recently discovered that toads congregated in the evening at two of his bee hives, which were low on the ground, and ate the bees as they crawled back and forth at the entrances. This difficulty was overcome by raising the hives two or more feet above ground. Apiaries could be easily protected in a similar manner, or by constructing a low wire fence entirely around the establishment.

It is not probable that toads will eat their own young. If such a cannibalistic habit occurs it must be uncommon. During May, 1934, fifteen young toads, slightly over ¼ inch in length, were placed in a cage with 25 large toads. These young ones have not been eaten after two months of close confinement with their larger brethren.

Dr. Williams kept two toads under observation for 10 months and recorded in his notes some very interesting facts relative to their feeding and other habits. These observations started during February, 1933, and extended to the end of the year. Toads moult the skin frequently during growth. Dr. Williams' observations on the process of moulting, as taken from his notes, follow:

> After feeding Bufo No. 2, I noticed that it soon lost interest in further food and, at a little provocation, flattened down with a hiss. It was occupying a small flower pot. At about 9:18 p. m. it could be seen that it was shedding its skin. The skin had evidently split on the back from posterior forwards, sliding or rolling down the sides. The new, exposed skin was very moist, warty and paler than the old coat. I noted the skin slip down and off one of the large parotid glands and seemingly over the face. The toad, which seemed to be in considerable discomfort, would squirm, contracting the belly and pushing under it with the hind limbs, lifting itself up and also pushing forward with the hands on each side of the mouth, where a dark strip of skin could be seen leading into the mouth. Every now and then it would open and shut its mouth, sometimes closing the eyes and giving the impression of yawning, but really swallowing the dark rolled up skin. The tongue, of course, was not extruded. The moulting, I think, occupied less than 20 minutes. A few minutes thereafter the Bufo resumed its appetite, swallowing the two large gecko lizards presented.

Dr. Williams succeeded in inducing one of the confined toads to eat a half-grown frog tadpole, when held before it, but when given a young frog *(Rana rugosa)* about 1½ inches long, an attempt was made to swallow it, but it evidently proved highly distasteful to the toad, for it was immediately disgorged and refused thereafter. He hand fed these toads for many months until one could be held on the hand, when it would snap up the lizards, grasshoppers, etc., presented. Dr. Williams states in his notes that:

> When ill-disposed, as during the daytime, they will swell up and hiss, when disturbed. When in the open they may leap off; when in a flower pot or corner, the head is often lowered, giving it a frowning or baleful look and the inflated toad may, apart from hissing, further show its displeasure by quite powerfully butting at an offending hand.

This toad can certainly see a small moving object some feet away from its body. Dr. Williams observed that the toads in his cage could distinctly see moving objects 3 feet distant.

It is remarkable that toads can swallow stinging wasps and bees without much apparent discomfort, since the effort to sting must continue for a few moments, at least, after the insect has been swallowed. It is even more remarkable that so muscular and venomous a creature as a centipede will also be taken as food. On the subject of centipedes and toads, we quote further from Dr. Williams' notes:

I customarily give the toads decapitated Scolopendra centipedes. This evening (September 25, 1933) Bufo No. 2 promptly grabbed one, head end foremost. It had great difficulty swallowing it, for the posterior legs of the centipede made very fast to the toad's foreleg so that it could not be disengaged. Bufo became quite stirred up, hopped about and headed plump into the flower pot, striving mainly to pull loose, not however letting go the fore end of the centipede. Finally I helped it loose and the centipede was swallowed. Bufo No. 1 was then given a large decapitated centipede, which it took. This was followed by tremendous activity on the part of the toad. It plunged about and used its arms in an essay to swallow the centipede, which had secured a grip with its hind portion on the toad's breast. Finally the toad swallowed all but the last pair of legs of the centipede, which hooked over the toad's mouth, but at last the centipede disappeared wholly inside.

The evening song of the male toad can now be readily heard on quiet evenings in taro patches, rice fields and reservoirs, where the species is well established. The sound can be easily distinguished from the harsh, rasping croak of the common frogs which are found in the same localities. The song can perhaps be best described as a rapid succession of deep, flute-like notes. By some, it has been described as resembling the sound of a distant diesel engine; others have compared it with the muffled sound of a motorcycle in the distance. The females utter clucking, complaining sounds sometimes when disturbed, but are not considered as finished and ardent vocalists as the males.

Attempts to breed this toad in confinement have been unsuccessful. Two cages at the Experiment Station contain toads from 13 to 16 months old, but, to date, no eggs have been laid in the water to which they have constant access. These toads have eaten thousands of insects during the year or more of confinement, have grown rapidly and appear perfectly normal in every respect. Investigators of toads in other parts of the world have also found that confined toads are usually sterile, or at least do not multiply.

Toads will wander far from the points where originally liberated. They do not necessarily require reservoirs, streams, ponds or swampy places after they have once passed through the tadpole stage and gone ashore. Their food is apparently all taken on land. We have not seen them feed while in water, excepting when snapping at insects at the edge of the water. For multiplication, however, the toad requires water for the deposition of the eggs and the development of the tadpoles.

There have been a few records kept on the length of life of toads kept in confinement in other countries. From these records it is evident that a toad will live for many years. We have seen one authentic published account of a European toad *Bufo vulgaris,* which was kept in a box and provided with food and water for 12 years. At the end of this period the toad remained unchanged and normal. We can conclude that in Hawaii the death rate, as compared with the birth rate, will be very low until many more years have elapsed.

Water and Cane Ripening

By Constance E. Hartt

This paper reports a preliminary study of the formation and translocation of sugar in cane plants deprived of water, compared with plants supplied with water. Among the many important questions to be answered by research of this nature, the following may be mentioned: Does photosynthesis (manufacture of sugar) continue in a leaf of a cane plant in the wilting condition of ripening off? What is the effect of withholding water from the plant upon translocation of sugar from the leaves to the stems? Does the sugar content in a cane stick actually increase due to the checking of growth during ripening, or is the improvement of the juices due merely to a decreased dilution with water? In short, is the sugar planter justified in withholding water approximately three months before harvest or not? The data here reported are the results of a single experiment only and as such serve merely to introduce the subject. No attempt should be made to draw final conclusions as yet.

Methods

The plants used in this experiment were of the variety D 1135 and were obtained from R. J. Borden. They were twelve months of age. The plants, which had been grown for another purpose, had not received uniform treatment; to some had been given lime, others molasses, or other soil amendments. The plants receiving different treatments were equally distributed in the four series of the present experiment. The pots of plants, which had been outside, were transferred to the greenhouse. They were then subjected to a series of preliminary studies by H. A. Wadsworth, who collaborated in this experiment. The treatment consisted of withholding water from all the plants and making daily growth measurements to determine when the water content of the soil reached the wilting point. As shown by Wadsworth (31) at the wilting point cane ceases to elongate, which results in a flattening of the growth curves. All of the plants used in this experiment were subjected to these preliminary tests, thus all of the plants had been at the wilting point several times before the experiment had commenced. At the time of the experiment half of the plants were receiving a plentiful supply of water, but previous to that time water had been withheld and elongation had ceased temporarily. This point must be considered in evaluating the results of this experiment, as it is recognized that the control plants were not normal. However, at the time of the experiment the control plants were receiving water and were growing, whereas the experimental plants were not receiving water and had ceased to elongate.

All of the plants were put in the dark Saturday morning, June 2, 1934. The lecture hall of the Experiment Station was used for this purpose, having been rendered absolutely dark under the direction of H. L. Lyon and R. E. Doty. Half of the plants (including some supplied with water and some deprived of water) were returned to the greenhouse at 9:30 p. m. Sunday. These plants received light beginning about 6 a. m. the following day. The plants which remained in

the dark were sampled at 8 a. m. Monday, having been in the dark about 45 hours. Those which were returned to the light were sampled at 1 p. m. the same day, having received moderate sunlight for about seven hours. Thus there were four groups of plants, herein designated dark wet, dark dry, light wet, and light dry.

Sampling was conducted as follows: All of the sticks were cut at the point of attachment of the lowest living leaf sheath. Counting the leaf with the highest visible dewlap as No. 1, leaves 1, 2, and 3 were taken from each of eight or ten sticks in each series. The blades were separated from the sheaths, wiped, and ground (midribs included) with a Russwin Food Cutter, and were sampled immediately. The sheaths of the same leaves were ground and sampled similarly. The stems, which included green leaf millable cane and non-millable stem, were cut and ground and sampled. No determinations could be made with the dry-leaf cane, which Mr. Borden needed for his own experiment.

The ground material was thoroughly mixed. Duplicate samples were placed in weighed aluminum boxes and weighed immediately for moisture determinations. After the addition of 1 cc. of hot 95 per cent alcohol, these boxes were placed in a vacuum oven at 90° C. and dried to constant weight. Duplicate samples were weighed and plunged immediately into boiling 95 per cent alcohol, in flasks containing one gram of $CaCO_3$, for neutralization of acids. These samples were stored in the dark until analyzed. Sugars were extracted from the samples with successive treatments with hot 50 per cent alcohol followed by ether and 95 per cent alcohol. Determinations of total and reducing sugars were made on the extracts, using the Munson and Walker (22) method and the Bertrand (2) titration. Citric acid was used for the inversion of sucrose. The residue after extraction was oven dried, powdered, and thoroughly mixed. Samples of the dried powder were used for the determination of polysaccharides by the method of hydrolysis with HCl (1). Other samples were used for the determination of starch by the Taka-diastase method of Shriner (28).

Results

Moisture percentages are given in Table I, which shows that the plants supplied with water had higher percentages of water in the blades, sheaths, and stems than

TABLE I

Moisture Percentages in Cane Supplied With or Deprived of Water

Series	Blades	Sheaths	Green-Leaf Cane
Dark dry	67.89 ± 0.171	79.63 ± 0.088	84.36 ± 0.071
Dark wet	70.72 ± 0.248	85.21 ± 0.081	88.52 ± 0.043
Light dry	66.64 ± 0.014	76.30 ± 0.052	84.16 ± 0.014
Light wet	69.57 ± 0.162	84.20 ± 0.055	87.83 ± 0.088

the plants deprived of water. The plants harvested in the light contained smaller percentages of moisture than those taken in the dark, indicating a decrease in moisture percentage during the day, which has already been reported in another experiment (15). Of the three organs studied, the blades were the driest and the sheaths were intermediate in moisture content.

Because of the differences in moisture percentage shown in Table I, the data for sugars and polysaccharides are not expressed on the wet-weight basis. Two methods of expression are used, the usual moisture-free basis and the residual dry-weight basis. Because of the fluctuations in carbohydrates at various times of the day, the second method is desirable, as mentioned by Denny (9). The residual dry weight equals the dry weight from which are subtracted both the total sugars and polysaccharides. It will be noted that when calculated on the residual dry-weight basis the probable errors are greater than on the moisture-free basis. This is probably because the duplicate results for polysaccharides did not agree as closely as the other determinations. However, most of the results show significant differences. Differences are greater on the residual dry-weight basis than on the moisture-free basis, and do not always show the same trend. Where there is a difference in trends indicated by the two bases of calculation, it is felt that the results calculated on the residual dry-weight basis are the more reliable, as explained by Denny. This is because it is mainly the carbohydrates that are undergoing change in amount, thus the residual matter after subtracting the carbohydrates represents a relatively stable and constant fraction, and calculations on the basis of this unchanging residue should give a true measure of the relative change in two different samples, as explained by Denny. The results are expressed on the moisture-free basis for purposes of comparison with other data but the discussion will be based upon the residual dry-weight method of calculation.

The results of the determinations of reducing sugars, sucrose, polysaccharides, and starch are presented in Table II.

If the percentages in the plants taken in the dark are subtracted from the percentages in those taken in the light, an estimate of the increase or decrease during exposure to light is obtained. This has been done and the results are given in Table III. The trends on exposure to light are also shown graphically in Figs. 1 and 2, the former showing the results on the moisture-free basis, the latter on the residual dry-weight basis.

Reducing sugars in the blades show a real increase in the plants deprived of water but not in the others. When calculated on the residual dry-weight basis this difference is more conspicuous than on the dry-weight basis. Therefore the reducing sugars tended to increase in the blades of the plants deprived of water but not in those supplied with water, during exposure to light. This could be explained as follows: greater photosynthesis in the dry blades, slower translocation in the dry blades, or greater use of sugar in growth in the wet blades. The second two possibilities are the most reasonable.

Reducing sugars in the sheaths decreased more in the plants receiving water than in the plants deprived of water when the results are calculated on the residual dry-weight basis, but the reverse on the moisture-free basis. The results on the residual dry-weight basis indicate greater growth and/or greater translocation in the plants supplied with water.

Reducing sugars in the stems show significant differences on the residual dry-weight basis but not on the moisture-free basis. The stems of the plants deprived of water increased in reducing sugars but the stems of the controls decreased.

This could be explained by greater growth of the latter or by translocation of reducing sugars into the lower part of the stick.

Sucrose increased in the blades of both series, a greater increase occurring in the controls than in the blades of the plants deprived of water, on both bases of calculation. This could be explained by greater photosynthesis or greater sucrose synthesis in the blades of the controls, or poorer translocation of sucrose from the blades of the controls, or translocation of sucrose from the stems into the blades of the controls. The second suggestion is not probable inasmuch as water is the medium in which translocation occurs. The last suggestion might be true if the permeability of cell membranes increases during drying, in which case adding water might easily wash sucrose up into the leaves. This, however, should have taken place at night as well as by day, but there is no evidence of that occurring since the blades of the plants supplied with water became so low in sucrose during the night.

Therefore, the best explanation of the sucrose percentages in the blades is better synthesis of sucrose (or photosynthesis) in the blades of the plants supplied with water. Sucrose in the sheaths and stems shows the same trends on both bases of calculation, an increase in the plants deprived of water and a decrease in the controls.

Polysaccharides increased in the blades during exposure to light, the increase being slightly greater in the plants deprived of water than in the controls, on both bases of calculation. In the sheaths and stems there was a decrease in polysaccharides, a greater decrease in the plants supplied with water than in those lacking water.

The percentages of starch were small and showed little variation. Significant differences were not obtained in the blades, and only small differences in the sheaths. The results calculated on the residual dry-weight basis show that in the stems there was an increase in starch in the plants deprived of water, but in the stems of the controls, starch decreased during exposure to light.

The percentages of starch were subtracted from the percentages of polysaccharides. Table III shows that the polysaccharides other than starch occur in cane in considerable amounts, and fluctuate during the day.

Total sugars were recalculated as glucose and added to polysaccharides to obtain an idea of the total reserve carbohydrate material. Table III shows that the total reserve carbohydrate material increased more in the blades of the plants deprived of water than in the controls, when calculated on the residual dry-weight basis. In the sheaths there was a decrease in both series, the decrease being greater in the plants supplied with water. In the stems there was a considerable increase in the total reserve carbohydrate material in the plants deprived of water, but a decrease in the controls.

TABLE II

Carbohydrate Percentage in Cane Supplied with or Deprived of Water

Series	Reducing Sugars m.f.*	Reducing Sugars res.*	Sucrose m.f.	Sucrose res.	Polysaccharides m.f.	Polysaccharides res.	Starch m.f.	Starch res.
Blades:								
Dark dry	1.592	1.926	2.437	3.147	14.15	17.628	1.173	1.543
	±0.008		±0.066				±0.041	
Dark wet	1.092	1.280	1.663	1.950	11.92	13.975	1.278	1.498
	±0.023	±0.028	±0.051	±0.061	±0.000	±0.012	±0.019	±0.672
Light dry	1.657	2.224	3.083	4.148	20.63	27.819	1.068	1.435
	±0.0005	±0.040	±0.109	±0.218	±1.209	±2.113	±0.058	±0.047
Light wet	1.068	1.380	3.432	4.440	18.12	23.427	1.226	1.584
	±0.003	±0.008	±0.013	±0.005	±0.214	±0.339	±0.033	±0.047
Sheaths:								
Dark dry	6.997	10.130	7.865	11.386	16.06	23.252	1.900	2.751
	±0.026	±0.029	±0.181	±0.257	±0.233	±0.346	±0.004	±0.005
Dark wet	10.795	18.609	5.687	9.802	24.88	43.070	1.795	3.091
	±0.004	±0.414	±0.009	±0.207	±1.032	±2.716	±0.021	±0.031
Light dry	3.861	5.273	9.659	13.275	13.37	18.363	1.803	2.470
	±0.154	±0.138	±0.526	±0.904	±0.643	±1.135	±0.008	±0.045
Light wet	8.192	11.765	5.058	7.271	17.12	24.592	1.990	2.830
	±0.002	±0.011	±0.197	±0.276	±0.286	±0.435	±0.039	±0.045
Green-leaf Cane:								
Dark dry	14.642	31.474	17.217	37.119	21.62	46.524	5.963	13.51
	±0.185	±0.028	±0.638	±1.813	±0.095	±0.753	±0.079	±0.064
Dark wet	13.104	32.229	21.805	53.806	24.35	59.820	4.476	11.120
	±0.191	±0.486	±0.157	±1.978	±1.240	±5.108	±0.162	±0.708
Light dry	14.567	40.142	22.973	63.154	26.03	71.890	3.695	10.131
	±0.198	±1.491	±0.232	±0.852	±0.892	±4.137	±0.133	±0.127
Light wet	12.688	26.094	14.232	25.056	24.44	50.348	3.441	7.096
	±0.134	±0.849	±0.458	±0.330	±0.076	±1.031	±0.063	±0.250

*m.f.: moisture-free basis; res.: residual dry-weight basis. See text for explanation.

TABLE III

Increase in Percentages of Carbohydrates during 7 Hours' Exposure to Light

Carbohydrate	Blades		Sheaths		Green-leaf Cane	
	m.f.*	res.*	m.f.	res.	m.f.	res.
Reducing Sugars:						
Water withheld	0.065	0.298	—3.136	—4.857	—0.075 (not sig.)	8.668
Water supplied	—0.024 (not sig.)	0.100 (not sig.)	—2.603	—6.844	—0.416 (not sig.)	—6.135
Sucrose:						
Water withheld	0.646	1.001	1.972	1.889	5.759	26.035
Water supplied	1.769	2.490	—0.629 (not sig.)	—2.531	—7.573	—28.750
Polysaccharides:						
Water withheld	6.48	10.191	—2.69	—4.889	4.41	25.366
Water supplied	6.20	9.452	—7.76	—18.475	0.09	—9.472
Starch:						
Water withheld	—0.105 (not sig.)	—0.108 (not sig.)	—0.097	—0.281	—2.268	8.780
Water supplied	—0.052	0.086	0.195	—0.261	—1.035	—4.024
Polysaccharides (excluding starch):						
Water withheld	6.678	10.299	—2.594	—4.608	6.677	28.745
Water supplied	6.253	9.366	—7.961	—18.214	1.129	—5.448
Total Sugars+Polysaccharides:						
Water withheld	7.06	11.443	—3.96	—7.695	10.24	59.918
Water supplied	7.90	6.974	—10.91	—27.555	—7.54	—38.834

*m.f.: moisture-free basis; res.: residual dry-weight basis.

Discussion

The amount of sugar in millable cane depends upon numerous factors, including the rate of photosynthesis in the leaves, the utilization of sugar in growth and respiration, the rate of translocation from the blades through the sheaths into the stems, and the transformations among the carbohydrates in the stem including further synthesis of sucrose. One of the most important means possessed by the sugar planter which enables him to control the physiological processes within the plant is the regulation of the water supply. The common practice on irrigated plantations is to stimulate growth by adequate applications of water, and then withhold water for a period of approximately three months before harvest to decrease growth and enrich the juices.

The question arises as to whether the enrichment of the juices following the withholding of water, indicated by a decrease in quality ratio, is caused by an increase in sugar or by a decrease in water. If merely the latter, it may be that plantation men are deceiving themselves and that an actually greater tonnage of sugar would be obtained if irrigations were continued nearer to the time of harvest. It is known that water is necessary for photosynthesis and translocation, and evidence is presented in this paper which may indicate that both these processes occur better in cane plants adequately supplied with water. On the other hand, it is

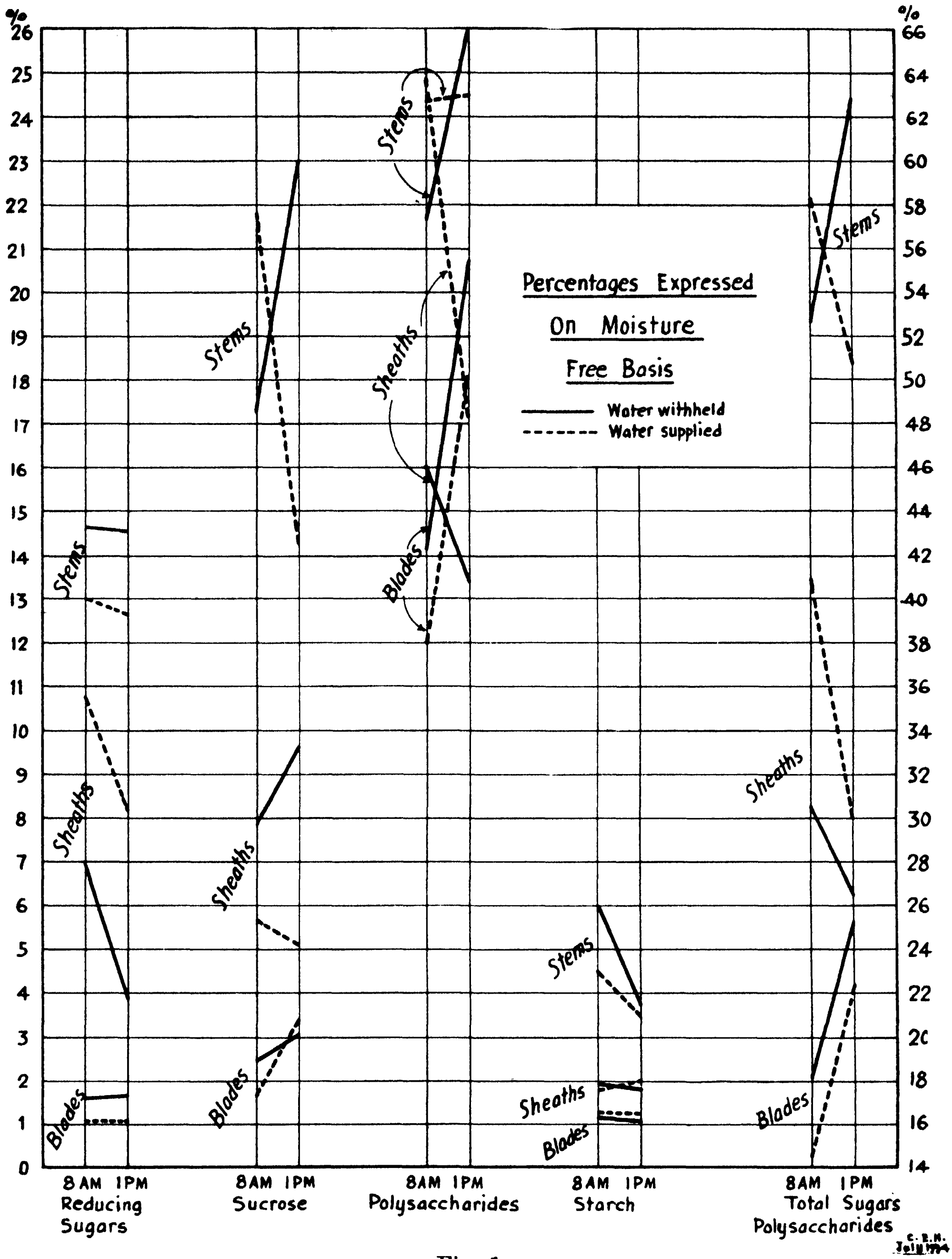

Percentages Expressed On Moisture Free Basis
Water withheld
Water supplied
Stems
Sheaths
Blades
8AM 1PM
Reducing Sugars
Sucrose
Polysaccharides
Starch
Total Sugars Polysaccharides

Fig. 1.

known that water stimulates growth and aids the hydrolysis of sucrose giving reducing sugars used in growth. In cane plants supplied with water, which is the greater, the loss in sugar due to stimulated growth or the gain in sugar due to photosynthesis? It is felt that the experiment now reported raises the necessity of studying this important question further, and the aim of the next experiment will be to obtain a decisive answer one way or the other.

The point at issue is somewhat clouded by the well-known fact that a rain occurring after a cane field has been dried off may result in a considerable loss in sucrose. Such a result would naturally follow hydrolysis due to increased moisture content. The point to be determined is rather this: Which will result in the greater tonnage of sugar, the usual process of withholding water for about three months prior to harvest, or continuing the irrigations?

This question cannot be fully answered from a practical standpoint without a due consideration of the sugar-producing value of the water that is withheld from a given field prior to harvest if placed on other fields where it is needed. This study does not enter into that phase of the question but gives recognition to it as an important part of the practical issue.

The present opinion is not unanimously in favor of withholding water. Rao (25) states that the onset of rains when the cane is ripe lowers the sucrose in the juice by inducing shooting of the buds, and that continuous moist weather without a well-defined ripening season has a similar effect on the juice. Verret, Mangelsdorf, and Lennox (30) report a cane ripening experiment at the Honolulu Plantation Company, where the cane was at its best from about 40-90 days after the last irrigation. After that there was a rapid loss in production per acre, caused by a slight decline in cane tonnage and a marked decline in juice quality. Juices were best 70 days after the last irrigation. They state that over-ripening may result in loss of sugar, loss of growing time for the next crop and injury to ratoons. That the withdrawal of water is not essential in cane ripening is shown by the growth of cane on unirrigated plantations, where rains may be very irregular. It is shown in a more striking manner by an experiment of Lyon and Brodie (19) in which a cane plant was grown for 12 months in tap water. Naturally no ripening by water withdrawal was possible, yet this plant had a quality ratio of 7.3. Renton and Bond (26) report that the general tendency on irrigated plantations is to decrease the length of the non-irrigation interval before harvest, and that serious losses result if water is taken off too long before harvest. They report an experiment at Ewa which showed that restriction of irrigation tends to depress cane yields appreciably, at the same time favorably affecting the juices enough to just about offset the loss in cane so that sugar yields are comparable. Restriction of irrigation is not effective in increasing sugar yields. In an experiment at Ewa, irrigation 35 days before harvest gave higher cane yields and in another experiment gave better juices. Renton and Bond conclude that caution must be used in the restriction of irrigation and that further investigations of this problem are needed.

The effect of withholding water upon the ripening of cane is really a physiological problem, since so many of the processes occurring within the cells of the plants are involved. Water unites with carbon dioxide in the process of photosynthesis, so that water is absolutely essential for the formation of sugar. Water

also affects photosynthesis indirectly, by maintaining the turgidity of the cells thus keeping the stomata open and allowing continuous absorption of carbon dioxide. The indirect effect upon photosynthesis is greater than the direct.

Water is the chief solvent in plants, it is the medium in which all chemical reactions occur in the plant cell, and it is the medium in which dissolved substances are translocated from the point of formation to the point of utilization or storage. The syntheses of higher compounds such as lignin, cellulose, polysaccharides, etc., are condensation processes requiring the withdrawal of water; but for the digestion of reserve polysaccharides a supply of water is necessary since digestion is a hydrolytic process. Thus, whether the processes occurring in a given cell at a given time will be mainly synthetic or mainly digestive depends largely upon whether the cell is losing or gaining water.

In considering which series of plants is the better, comparisons will be drawn and possibilities suggested, but no attempt will be made to draw a conclusion until the experiment is repeated.

The differences in moisture percentage are not large, although significant. The blades of one series of plants may undergo variation just as great during a period of 24 hours. The blades of cane plants growing in the field at the Experiment Station and receiving an adequate amount of water, varied from 66.56 per cent water (at 3 p. m.) to 70.75 per cent water (at 6 a. m.) on April 25 and 26, 1933 (15). It does not seem likely that the percentage of water in cane blades would decrease much more under the usual conditions of ripening, inasmuch as the plants used in the experiment now reported presented an appearance far worse than is usual in the field. It is recognized that withholding water decreases the photosynthetic surface by hastening the drying of the lower leaves; but it may be that the water content of the upper green leaves does not decrease enough to interfere seriously with photosynthesis. Brilliant (3) using the method of gas analysis found that with a loss of 41-63 per cent of the water content of the leaves of *Hedera helix* and *Impatiens parviflora* photosynthesis almost stopped, but a loss of about 39 per cent resulted in a rapid increase in photosynthesis. In the present experiment the decrease in water in the blades exposed to light was from 69 per cent (the "wet" blades) to 66 per cent (the "dry" blades), representing a loss of about 4 per cent of the water, which is so little that it may have had no ill effects upon photosynthesis. Miller (20) states that the effect of lack of water upon the closure of the stomata is greater than the direct effect upon photosynthesis. At the wilting point cane leaves do not droop as do the leaves of many plants, and it may be that the stomata do not close.

Reducing sugars, sucrose, and polysaccharides are all considered either direct or indirect products of photosynthesis. Table III shows that both reducing sugars and polysaccharides increased more in the blades of the plants deprived of water, whereas sucrose increased more in the blades of the plants supplied with water. Thus an answer has been obtained to an important question, as it would seem that photosynthesis occurs in the blades of cane plants at the wilting point. As mentioned in the results, the best explanation of the increase in sucrose is better synthesis of sucrose (or photosynthesis) in the plants supplied with water. It would seem that a plentiful supply of water favors the development of sucrose in the

blades, whereas a deficiency in water results in the greater synthesis of polysaccharides.

The results for reducing sugars, sucrose, and polysaccharides are consistent in sheaths and stems, and may be explained either by greater translocation or greater growth in the plants supplied with water. It is known that the control plants were growing but the others were not. However, the growth of the control plants during the 7 hours' exposure to light was almost negligible, having been estimated by Mr. Wadsworth as about a third of a centimeter per stalk in elongation. Growth during exposure to light will be accurately determined in the next experiment. If the decrease in sugar in the stems of the plants supplied with water was due to further translocation into the lower part of the stick, that should result in a greater percentage of sucrose in the dry-leaf cane of the controls, a point to be determined in the next experiment.

Possibly the blades of the plants supplied with water synthesized more sucrose than the others but the control blades were not growing while the control sheaths and stems were growing and using up both sucrose and reducing sugars.

Considering just the results herein presented, it would seem that the plants deprived of water were the better. Drying-off resulted in a considerable increase in sucrose in the green-leaf cane. Before reaching this conclusion definitely, however, the experiment must be repeated. The possibility remains that the loss of sugar in the green-leaf cane of the plants supplied with water resulted from translocation into the lower part of the stick.

Work with other plants indicates that lack of water decreases the rate of photosynthesis but increases the formation of sucrose. Kreusler (18) and Nagamatz (23) have shown that the withdrawal of water from a leaf decreases its photosynthetic activity. Thoday (29), using the half-leaf method, found that closure of stomata causes a lowered rate of photosynthesis when water is withdrawn. Dastur (5) quotes a series of references reporting that plants lacking stomata show less depression of photosynthesis upon withdrawal of water than plants having stomata. Dastur also describes a simple experiment and concludes that photosynthesis is dependent upon water content. Brilliant (3) found by gas analysis, using *Hedera helix* and *Impatiens parviflora,* that with a loss of 41-63 per cent of the water content photosynthesis practically ceased. A decrease of about 39 per cent, on the other hand, was accompanied by a rapid increase in photosynthesis. In a later contribution Dastur (6) presents results obtained by gas analyses using *Cineraria stellata, Spermannia africanum,* and *Abutilon Darwini,* which showed a close relationship between rate of carbon dioxide assimilation and water content. There was nearly a straight line relationship between assimilation rate and water content, in the same species. When comparing different species, in some cases leaves with low water content assimilated more rapidly than leaves with high water content. The theory is suggested that water shortage due to inefficiency of the conducting system eventually terminates the photosynthetic activity of a leaf. Dastur and Buhariwalla (7) found that the chlorophyll content is influenced by the water content. Dastur and Desai (8) using *Abutilon asiaticum, Ricinus communis, Helianthus annuus* and *Phaseolus vulgaris,* by gas analysis found that photosynthesis showed a closer relationship to water content than to chlorophyll

content. They suggest that the importance of water may be due to the rate of diffusion of carbon dioxide within the assimilatory cells, the removal of translocation products, and the velocity of the chemical stages of the process. Emmert and Ball (10) studied the effect of soil moisture on the availability of nitrate, phosphate, and potassium to the tomato plant, and suggested (with no experimental evidence) that one of the major effects of low soil moisture is the probable decrease in photosynthesis and general metabolic processes in the plant.

An increase in the formation of sucrose in plants deficient in water has been suggested by various workers. Iljin (17) studied many species of plants in natural habitats and found more sugar in leaves in dry habitats than in wet. Leaves of *Rumex crispus* and *R. conglomeratus* contained almost twice as much sugar withered than when turgid. His work, however, is open to criticism because no mention is made of the intensity of light in the different habitats, and no account is taken of possible effects on translocation. Holman (16) quotes Neger (24) and Molisch (21) who found that wilting hastens the disappearance of starch from starch-filled leaves. Schroeder and Herrmann (27) found that in wilting nasturtium leaves the sucrose content increases at the expense of starch, a change of which the mechanism is not fully understood. Greathouse (12) using five varieties of soy bean, sunflower, milo, and cabbage, found that with the approach of maturity the moisture content of the leaf tissue decreases rapidly, causing a corresponding increase in concentration and osmotic pressure of the sap. Plants hardened to drought have increased osmotic pressure, decreased moisture content, increased sap solutes such as sugar, and increased bound water.

Although some of the evidence just presented is open to criticism, yet the general idea seems to be that a plentiful supply of water favors photosynthesis, whereas a lack of water favors sucrose synthesis. If sucrose is the first sugar in photosynthesis, then the evidence presented above is conflicting. This is further evidence that glucose is one of the first products of photosynthesis and that sucrose is made by condensation, inasmuch as the withdrawal of water favors condensation. That this is true in cane has been suggested in previous reports (15), as well as the suggestion that the enzyme invertase is important in catalyzing the synthesis of sucrose (13, 14). Evidence that the reducing sugars condense to sucrose is found in the present experiment. If the percentages of sucrose and reducing sugars in the blades and the sheaths are compared (Table II), it will be seen that in the blades of each series there is more sucrose than reducing sugar. In the sheaths, however, there is a difference depending upon the amount of water; those of the plants deprived of water having more sucrose than reducing sugar, those of the plants supplied with water having more reducing sugar than sucrose. In the stems, again, in each series there is more sucrose than reducing sugars, except for the stems of the plants supplied with water in the light. It would seem that hydrolysis of sucrose to reducing sugars aids in the translocation of sugar through the sheaths, that the reducing sugars are condensed to sucrose upon reaching the stems, and that withholding water aids in this condensation.

Table II shows that the percentages of reducing sugars, sucrose, polysaccharides, and starch increase from the blades to the sheaths to the stems, with the exception of polysaccharides in the "light dry" sheaths. Thus in the process of

translocation sucrose seems to move against the diffusion gradient. This has been reported for cane previously (15), and in other plants by other workers, and the suggestion made that sugars may never actually pass from a cell containing less sugar to one containing more. In both sheaths and stems there is more storage tissue than phloem, and both sheaths and stems have relatively more storage tissue than do blades. The greater percentages of sucrose and reducing sugars in the sheaths and stems than in the blades may be due to the fact that the sugar in the sheaths and stems is spread out in more cells, in which case the direction of translocation would be with the diffusion gradient.

Possibly another factor aiding in the translocation of carbohydrates is their interconversion. This may be an important function of polysaccharides. Polysaccharides other than starch occur in large quantity in cane, raising the questions of what they are and what are their functions. Very little work has been done upon the polysaccharides of cane. The method of hydrolysis with weak acid gives results which probably include hemicelluloses, pentosans, plant mucilages, pectic compounds and other substances. Probably all of these occur in cane. Browne and Blouin (4) quote a proximate analysis of cane by Halligan and Agee, showing pentosans in leaves, 5.49 per cent; stalks, 3.04 per cent. The hydrolytic products of purified bagasse digested with caustic soda included some xylan and araban. Microchemical tests conducted by Crutchfield (personal communication) showed the presence of araban and xylan in the leaf and the stem. Farnell (11) studied the pectic substances of sugar cane fiber and reported the presence of pectinogen and pectin. It is felt that there is need for further study of the composition and functions of specific polysaccharides in cane.

Summary

1. Evidence is presented indicating a greater synthesis of sucrose in the blades of cane plants supplied with water than in those deprived of water. Some photosynthesis occurs in sugar cane at the wilting point.

2. Differences in reducing sugars, sucrose, and polysaccharides in the sheaths and stems may be explained by assuming either greater utilization of food by the plants supplied with water during seven hours' exposure to light, or better translocation in the same plants.

3. The experiment will be repeated in an attempt to obtain a decisive answer to the question, which is the better plant? Criticisms and suggestions from anyone interested will be appreciated.

Acknowledgments:

The author is indebted to Mr. H. A. Wadsworth for his collaboration in the experiment; to Mr. Ralph Borden, who supplied the plants; to Dr. H. L. Lyon and Mr. R. E. Doty for directing the darkening of the room; and to Miss Ada Forbes and Miss Irma Linneman for their help during the sampling and analysis of the plants.

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Phosphate Fixation in Hawaiian Soils—III

By L. E. Davis

The first paper of this series, written by Hance (3), presented a comprehensive discussion of the fixation of phosphates in Hawaiian soils. The second paper, by Ayres (1), dealt with the geographical variation of fixing power, the methods of studying the phenomenon in the laboratory and the rate at which applied phosphate is fixed.

The present paper will deal with the mechanism of phosphate fixation, that is, it will attempt to answer the question: What takes place in the soil when applied phosphates are fixed?

In order to discuss this question adequately it becomes necessary to distinguish two related but different connotations of the expression "phosphate fixation." The most important sense is that phosphate fixation is a process by which applied phosphate is rendered unavailable to the crop. The second meaning is that applied phosphate, which is at first in solution, goes out of solution when mixed with the soil. These two concepts are not quite identical because of the fact that certain almost insoluble phosphate compounds which may be precipitated under certain conditions may be still soluble enough when in contact with plant roots to slowly provide sufficient phosphate for the plants grown in the soil. For this reason simple chemical tests of phosphate fixation may not always correctly indicate that applied phosphate will be withheld from the cane due to fixation. An illustration of this fact is presented by Ayres, who found extremely high fixation in Hilo Coast soils, that is to say, these soils show an extremely high tendency to render almost completely insoluble any phosphates applied. Nevertheless, as Ayres points out, these soils are highly productive. Although they show indications of phosphate deficiency in Mitscherlich tests, and in a certain visible response to phosphate applied in

special ways in the field, increased yields due to phosphate applications, where the final yield of cane is measured in the ordinary phosphate field experiments, are not generally obtained. (There are, however, a few exceptions.) The status of these soils with respect to their need of phosphate is one that invites further study. On the other hand, there are a number of Hawaiian and other soils which fix phosphate strongly, as shown by chemical and other tests, so that as a consequence there is a decided and unquestionable deficiency of that nutrient. In many of these soils, although little or no response is shown to light fertilizations, the deficiency symptoms are largely overcome by heavy applications.

Phosphate Fixation as a Chemical Phenomenon:

We shall first discuss the chemical aspect of fixation. What happens when phosphates are removed from solution by contact with soil? We shall find that more than one thing can happen and that while some processes cause the formation of rather insoluble phosphates similar to reverted phosphate, which are, nevertheless, a source of plant food, other reactions lead to the formation of complex materials in the soil which are probably far less able to yield phosphates for the use of the plant.

Among investigators there has been considerable controversy as to the mechanism of phosphate fixation. In the opinion of the author this controversy has arisen largely because one worker was studying a type of soil in which one process was dominant, while another investigator was interested in soils in which a very different process was responsible for most of the fixation.

Fixation Caused by Precipitation:

Up to within a year or two ago almost everyone subscribed to the opinion that phosphate fixation was due to a process whereby calcium, magnesium, iron, aluminum and manganese were dissolved from the soil or replaced from the replacement complex and then formed rather insoluble compounds with applied phosphates. Russell (5), p. 199, is quite emphatic upon this point, as are other authorities. There is no doubt that this process occurs in most soils to a large extent, probably in all soils to some extent. Apparently while some plants may have difficulty in utilizing some of these insoluble forms, others undoubtedly can use some of them as shown by Marais (4) and recently by Ward and Gow, as described by Hance (3). It is very probable that in areas like the Hilo Coast this type of fixation is very important. Since phosphate so fixed is not really withheld to a harmful degree from sugar cane with its growth period of from 15 to 24 months, we shall pass on to the discussion of the more serious types of fixation which have been studied in this laboratory during the past year. In collaboration with Ayres the writer is studying possible methods for distinguishing the less troublesome types of fixation from the more harmful ones.

All of the phosphate compounds mentioned above, while rather insoluble under certain conditions of acidity or alkalinity, are somewhat more soluble at higher or lower pH values. One phosphate compound not listed above, titanium phosphate (a substance of variable composition, due to the formation of complex basic salts), is

quite insoluble in very acid up to moderately alkaline solutions. If this compound could be formed we should have a very difficultly available form of phosphate. Hawaiian soils contain large amounts of titanium and it is conceivable that under certain conditions phosphate might be fixed as titanium phosphate. However, it has been found in this laboratory that in certain high-fixing soils titanium is not responsible for more than a trace of the phosphate fixed.

Two very acid phosphate solutions were prepared. The pH of these solutions was very low, 0.5, about the pH of a solution made up with 3 cc concentrated hydrochloric acid in 100 cc of water. At this acidity all the phosphates mentioned above, except titanium, are quite soluble. (There are, of course, other insoluble phosphates of rarer metals not found to any extent in our soils.) To one of these solutions hydrogen peroxide was added but not to the other. Hydrogen peroxide prevents the precipitation of insoluble titanium phosphate. Now when soil was added to each of these solutions we should have expected less fixation in one case than in the other if fixation were due to the formation of titanium phosphate. Nevertheless the fixation was the same for both solutions. A solution of titanium sulfate was added to each filtrate obtained from the mixtures. In one case a precipitate was formed, in the other, containing hydrogen peroxide, none was formed. We see that the results were not due to any incapacity of the phosphate to precipitate titanium in one case or to failure of the hydrogen peroxide to prevent precipitation in the other case. The explanation is that the titanium compounds of the soil are so insoluble that no more than a mere trace of titanium went into solution to precipitate phosphates.

Precipitation Not the Only Cause of Fixation:

Experiments in this laboratory have demonstrated that when all the readily soluble substances which could form insoluble phosphate compounds have been removed by percolation of dilute acids or solutions of salts through the soil, the soil still possesses a pronounced fixing power. In fact in some cases it is only slightly decreased. There is thus some mechanism of fixation other than the formation of these precipitates.

The same fact is shown by the pronounced fixation in very acid solutions which is as great as that in neutral or alkaline solutions. In another experiment a soil from upper Manoa Valley was shaken for many days with very acid phosphate solutions. The pH of the solutions never became greater than 0.70. None of the phosphates except titanium could have been precipitated under these conditions. Nevertheless, as can be seen from the data below, there was pronounced fixation which increased slowly as time went on.

Time—Days	Per Cent Fixed
⅜	30.8
2½	45.0
6	55.4
10	65.7
14	72.8
27	86.5

Now since it is clear that in these acid solutions substances do not leave the solid soil and form insoluble compounds in the solution by reacting with the phosphates present, there is only one alternative: the phosphates must leave the solution and join the solid soil materials to become part of them.

Soil Colloids:

There are two ways in which this situation might occur. During the long process of weathering the original soil minerals have been decomposed into a very large number of extremely small particles. Under ordinary field conditions these particles are rather loosely held together to form the more or less continuous mass of an untilled field soil, which is then broken up into clumps by cultivation. Under certain conditions when the soil is quite moist and then thoroughly stirred, and also to some extent when it is not stirred, these particles can be separated from one another. If the particles remain separated they do not settle out rapidly but remain in suspension for some time. When the amount of water is small such a suspension becomes a pasty mass. In the field this process is called puddling; in the laboratory it is called peptization or dispersion. In most soils only a small percentage of these particles are as minute as those usually studied in colloidal chemistry and which are technically known as colloids. However, there is no sharp division of particle size below which the particles exhibit the properties of colloids, or above which they do not. Since the soil particles approach the size of what are usually called colloids, they partake to a large extent of the properties of the latter and are usually, therefore, called soil colloids. One of the consequences of dividing a material into very small particles is to increase the total surface; another result may be an increase in the curvature of the surface.

Fixation Due to Adsorption:

All surfaces have the capacity to attract and hold in some way various substances. This property is called adsorption. Adsorption tends to be greater on curved surfaces than on plane surfaces. An enormous number of colloidal particles, presenting a large extent of sharply curved surface may have a high power of adsorption. An extremely porous material will have a similar power since there is then a large internal curved surface. It is the power to retain certain colored substances that makes bone char so useful in sugar refining.

It is conceivable that adsorption plays a part in phosphate fixation. It is probable that it does not play a very large part. In the first place the power of soils to adsorb most acidic radicals, such as sulfates, chlorides, nitrates, etc., is not very great. From the data above we see that in 27 days, even in a very acid solution, 86 per cent of the phosphate had been fixed. In an experiment, the data from which it is not necessary to present in detail here, ammonium chloride solutions were shaken with portions of this Manoa soil. Less than 3 per cent of the chloride was fixed at any concentration over a wide range, and it is by no means certain that all of that 3 per cent was fixed by adsorption. It should be surprising to find that phosphates are an exception unless there were some specific chemical relation between phosphates and the soil minerals to cause such an extraordinary increase in adsorption.

Occasionally it is stated that in phosphate solutions we have PO_4 ions which are trivalent negative ions. Trivalent negative ions have the power of combining with three times as much potassium or sodium as monovalent ions of which chloride ions are an example. It is further stated that in general, trivalent ions are more strongly adsorbed than monovalent ions like chloride ions, and that this would account for the alleged great adsorption of phosphates. There are two misconceptions in these statements. In the first place in acid, neutral, and moderately alkaline solutions phosphates yield only extremely small quantities of trivalent PO_4 ions, a fact well known to chemists. The ions present in phosphate solutions at neutral, acid or moderately alkaline reaction are the monovalent ions H_2PO_4 and the divalent ions HPO_4. In the second place there is no evidence in the literature to show that even where we certainly have such ions the adsorption of ions increases greatly and consistently with their valence.

True adsorptions are usually very rapid and are completed in a matter of minutes rather than days. We see phosphate fixation still not completed after 27 days. In another experiment with this Manoa soil, in a neutral solution, fixation was not completed at the end of 85 days of constant agitation of the mixture of soil and solution. Unless we have no other explanation, adsorption is not a very satisfactory one.

Solid Solutions and Absorption:

There is, however, another way in which a solid material can react with various substances in a solution which is in contact with the solid substance. Solids are not quite as impervious as we ordinarily suppose. Under certain conditions it is possible for one substance to be so intimately interfused with another that we have in the solid state a true solution. Such solutions are called solid solutions and they are usually formed by the cooling of liquid solutions. Some slags, alloys, etc., are examples. Some melts do not cool to a system of solid solution but separate as distinct, although very minute crystals. A solution of common salt in water, when frozen, becomes a mixture of ice and salt.

Solid solutions can also be formed by liquids, solids or substances in solution diffusing into the solid material. This process is usually very slow and it has not been very widely studied, so examples are not numerous: gases dissolve in certain metals, water is taken up by many solids (in many cases this is probably adsorption), thallium nitrate in aqueous solution diffuses into solid potassium nitrate, many organic liquids diffuse into organic solids, mercury is taken up by many metals. In the latter case there is a special reason for the reaction. The metals tend to dissolve in the mercury with the formation of mercury-metal compounds. These substances are called amalgams.

When a chemical reaction occurs between the diffusing substance and the material into which it diffuses, the tendency for fixation becomes very great. Such a process is called absorption. Adsorption, the fixation of substances upon surfaces, and absorption, the fixation of substances in the interior of solids, are sometimes collectively called sorption, a term which is useful when we are certain that either adsorption or absorption occurs but are not quite certain which takes place.

New compounds are formed and may be said to exist in solid solution along with the absorbent (the original solid material) and the absorbed substance.

Gels—A Form of Colloids:

Before applying this discussion to the fixation of phosphates we must digress a moment. Besides the three ordinary states of matter, gaseous, liquid and crystalline (or solid), we have mentioned what is in a sense a fourth state, that of extreme division or dispersion into colloidal particles. It is possible to speak of a fifth state. This arises when under certain conditions the colloidal particles come together and coalesce, usually with considerable water, to form gelatinous masses. A few drops of acid rapidly mixed with common water glass will form such a gelatinous mass. These substances are called gels. (The ordinary suspensions of dispersed particles are called sols.) Now it is generally believed that in gels the original minute particles are still present and are either surrounded by water or consist of a network which encloses the water. There is still considerable uncertainty about the structure of gels.

Gels have a pronounced capacity for sorption. Generally this is considered to be due to adsorption on the surfaces of the small particles composing the gel. But in a sense the gel as a whole may be said to absorb substances. The rate is sometimes quite slow, particularly with some gels into which diffusion is slow. It is possible to consider sorption by gels as a case intermediate between adsorption by sols and absorption by solids.

Fixation Due to Absorption:

In soil we undoubtedly have present besides organic matter, air and water, crystals and amorphous solids. Some of the solids are present, as we have seen, in a state of fine division. It is also probable that gels or gel-like flocs are present. There is some controversy upon this point which need not concern us here. The colloidal matter in an undispersed dry soil has many of the characteristics of aged, desiccated gels which, by vigorous peptization with both mechanical and chemical agents can be moderately dispersed. This consideration makes clear a paradox. The relative fixing power of a soil may be related to the amount of colloidal matter (gel) in the soil; it is not necessarily related to the number of very small particles as estimated by a sedimentation analysis.

Whatever may be the best term to use in describing the solids in the soil, the fixation of phosphate has all the characteristics of absorption. The fixation is rapid at first, which may be due to reactions occurring at or near the surface; subsequently the rate decreases, but the process continues for a long time, which one would expect if the diffusion is quite slow. Fixation is specific, that is, certain substances, phosphates and arsenites are strongly fixed; others, such as chlorides, sulfates, ferrocyanides (in alkaline solutions, the latter should yield not only trivalent ions, but quadrivalent ions) are not.

Phosphate fixation may then be considered as due to three processes: (1) bases such as Ca, Mg, Fe, Al, Mn present in the soil go into solution and react with phosphates to form insoluble phosphates. (2) phosphates are adsorbed upon the

colloidal surfaces. (3) phosphates slowly diffuse out of the solution into some of the amorphous solids of the soil. They combine with materials in these solids. Probably hydrated iron and aluminum oxides combine with phosphates to form complex compounds. It is believed that in upland Hawaiian soils the third process predominates.

Only a part of the evidence for this picture has been presented. There is available a great deal of evidence experimentally obtained in this laboratory and some corroborative evidence in the literature, notably the results of recent researches by Dean (2). Certain characteristics of the equilibrium curves obtained from fixation experiments; the fact that more phosphate is fixed in acid solutions than in neutral or alkaline solutions; the fact that bases, such as potassium, are fixed along with the phosphate, etc., can be interpreted as evidence supporting the conclusions. The discussion of these points is, however, rather technical and is omitted.

Agricultural Significance of Phosphate Fixation:

In the first part of this paper we stated that there were two different meanings of the term "phosphate fixation". We shall now turn to the first meaning which is less technical and also of more importance to agriculture. Phosphate fixation means to the man who is concerned with sugar cane yields a process whereby, whatever the cause, the plant cannot find available a part, large or small, of phosphate applied as fertilizer.

Obviously phosphate precipitated in the form of compounds which readily yield phosphorus to the plant roots is not fixed in this sense. Such precipitation not only does no harm; it is of undoubted benefit in preventing excessive leaching of phosphate.

Beyond this, however, there are two things to consider in regard to the absorption of phosphates. In the first place the reaction is quite slow, even when the soil is finely powdered and continuously shaken with a large amount of solution. It is probably much slower when applied as a top dressing or when merely mixed with moist soil. During the interval following fertilization there must be at first considerable available phosphate and later appreciable amounts.

Phosphate Absorption a Reversible Equilibrium:

The second consideration is concerned with the very nature of the process. We have abundant evidence to show that phosphate absorption is a reversible equilibrium. In truth this fact constitutes part of the evidence in favor of the absorption hypothesis. By a reversible equilibrium we mean that the process has a tendency at all times to go in both directions and that this tendency is controlled by the relative amounts of the substance taking part in the process.

A crude analogy can be found in the state of affairs which occurs, for example, when a number of people are visiting a series of exhibits in different rooms at a county fair, and are permitted to pass freely from one room to another. The number of people passing from one room to another depends upon the number of people in each room to a certain extent. Some rooms are more crowded than

others because the exhibits are more interesting, but in general some people will leave when they cannot see or hear easily. This situation is quite different from an entertainment at a theater where the crowd enters at one time and later leaves in a body.

In absorption, as in most chemical reactions, the more phosphate in solution, that is, the more the solution is crowded, the more will tend to enter the soil and be fixed. For this reason one cannot speak of "the fixing power of the soil" as an absolute quantity in terms of pounds P_2O_5 per acre, or of "saturating the fixation complex". Likewise, the more phosphate fixed in the soil the more will tend to leave the soil and return to the solution. We shall now consider what happens when, as we say, the system reaches equilibrium. Then, there is obviously a balance set up. The important point is that at this time some phosphate must remain in solution; the amount may be very small. Instead of asking how much phosphate is required to completely saturate the soil, one should ask how much is required to retain a certain minimum concentration in the soil solution. This point has been emphasized by Ayres.

If the balance is upset in any way, an adjustment must take place. The balance can be temporarily upset by leaching out the phosphate in solution or by assimilation of that phosphate by plant roots. Now, if the amount of phosphate in solution is temporarily enough for proper nutrition of the plant more will be forthcoming from the fixed supply, provided the requirements of the plant are not so great that assimilation is very much more rapid than the reversal of fixation. There is, of course, a limit to this process since as the fixed supply decreases its tendency to enter the solution decreases also and the amounts available to the plant decrease. In this connection it may be noted that probably a highly dispersed soil not alone fixes phosphate more quickly but will also release it more rapidly. This fact may account for some of the apparent conflict between chemical tests and agricultural experience.

All this is quite different from the case of a plant obtaining its nutrition from a solution surrounding a solid compound which is not in solid solution. In this case the amount of the solid compound has no effect upon the amount which goes into solution. (The extent of surface exposed has an effect upon the rate at which the material goes into solution.) This is analogous to the case of an exhibit to which only a definite number are admitted at any time. Obviously the number of people in an adjacent room would not affect the number visiting this particular exhibit.

Conclusions

Phosphate fixation is not invariably an unmitigated evil. It is a means whereby applied phosphates are conserved and as long as sufficient phosphate remains available to the crop it is a blessing. Whenever high phosphate fixation is suspected in a field soil it is probably best to supplement the results of rapid chemical tests by other considerations to be obtained from more refined chemical tests, Mitscherlich tests, field experiments, and, most important of all, as shown in the case of the Hilo Coast soils, the general agricultural experience with the soils.

There are probably cases of moderate fixation of such character that response

to light applications is not apparent, but where moderately high applications would raise the level of phosphate fixed to the point where there is sufficient of this nutrient available. The question will then be asked: Can this expensive fertilization be followed by light applications for a number of years? This is, of course, the crux of the whole matter. There is a vast difference between a moderately great fertilization followed by light applications and the unwelcome prospect of continued heavy applications. There is, however, every reason to believe that once a reasonable available supply is made possible this can be maintained by light fertilizations for some time. Needless to say, if the uptake of phosphorus by the crop exceeds the amount applied as fertilizer, the soil will be gradually depleted again.

When fixation is so intense that only large fertilizations can raise the phosphate level sufficiently it is believed that fertilizer briquettes or the less soluble phosphatic materials will supply sufficient plant food without losing their phosphate to the fixation complex of the soil.

Summary

1. A theory of the mechanism of phosphate fixation is presented.

2. Two connotations of the expression "phosphate fixation" are considered. Not all phosphate removed from solution and therefore classed as fixed in one sense of the term is actually unavailable to crops and therefore fixed according to the second meaning of the expression.

3. Some phosphate is fixed by reaction with soluble or replaced soil bases to form precipitates.

4. It is shown that precipitation does not account for the greater part of fixation in upland Hawaiian soils.

5. The nature of soil colloids and their relation to phosphate fixation is discussed.

6. It is concluded that adsorption by the soil colloids is a minor cause of phosphate fixation.

7. The single alternative explanation for phosphate fixation is that phosphates are absorbed by the soil material, that is, they actually penetrate the solid phase to react and form new compounds in solid solution.

8. It is shown that while most of the absorbed phosphate is not immediately available, an equilibrium concentration of available phosphate is maintained in the soil solution.

9. Due to the slow rate of fixation, some available phosphate remains for some time after fertilization.

10. Fixation is not entirely harmful. It conserves the phosphate supply.

11. In some cases it may be feasible to build up a phosphate reserve by an initial heavy fertilization, followed by lighter applications. In other cases this may not be practicable, and phosphates should probably be supplied in briquettes or in insoluble forms.

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For Better Field Experiments With Fertilizers

By R. J. BORDEN AND Y. KUTSUNAI

These "plans of fertilization" and "arrangements of treatments" are offered as examples for better "Grade A" field experiments that are primarily concerned with fertilizer issues. We believe that results which may be obtained from such plans can be suitably interpreted and differences can be measured with considerable confidence that they are the effect of the treatments applied.

In the plans of fertilization that are given here we would avoid overly large single applications of soluble nitrogen or potash salts, with the feeling that such is a safer procedure to follow in our field experiment work. Hence, no single application of nitrogen greater than 100 pounds, or of potash greater than 150 pounds is recommended (unless size of dose is the variable being tested). Concerning phosphate, we believe that wherever possible this material should all be applied to plant cane in the furrow with the seed, and in a small off-bar furrow to ratoons as soon as they are started. We would generally avoid surface applications of phosphate, especially of the insoluble forms.

Naturally it is impossible to give plans to fit every condition that will exist. It will probably be necessary to make some changes in the constants that are suggested. One may wish to allow for more, or for less, of those plant foods that are not concerned in the differential treatments, depending on the available natural or soil supplies. However, it will be well to make sure that the amounts allowed for these constants will not become a controlling factor for the experiment.

In submitting arrangements of treatments we have indicated what we believe are the preferred layouts as well as alternative layouts that are acceptable. Our objectives for these preferred designs have been as follows:

(1) Either to locate the most desired comparisons on adjacent plots, thus making them suitable for analysis of the average yield differences by Student's method, or to arrange treatments in blocks (one plot of each treatment in each block) in a manner that is suited for the application of Fisher's analysis of variance to the results.

(2) To provide for a balance of a possible fertility slope that might exist in the test area and cause unfair comparisons.

(3) To reduce the border effect between treatments.

Thus several new arrangements are offered that appear to meet the desired objectives slightly better than some of the older arrangements have done in previously used fertilizer tests. These may not necessarily be preferred arrangements for all tests, since in some cases the harvest- and separation-errors of the outer lines of adjacent plots are liable to be greater than the errors due to border effect. Then too, a reduction in this border effect can be obtained if the differential fertilizer applications to adjacent plots are made on the inner side of each plot's border rows. However, these new arrangements are offered for consideration and trial in our efforts toward building for better field experiments with fertilizers.

SOME APPROVED "GRADE A" PLANS FOR FERTILIZATION AND ARRANGEMENTS OF TREATMENTS

Kind of Experiment: PLANT FOOD (PK)

Plan of Fertilization

Treat-	(1)	(2)		(3)		(4)	(5)	Pounds per Acre Totals		
ments	P_2O_5	N	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	200	40	0	60	0	50	50	200	200	0
B	200	40	100	60	100	50	50	200	200	200
C	0	40	100	60	100	50	50	200	0	200
D	0	40	0	60	0	50	50	200	0	0

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization

Treat-	(1)			(2)		(3)	(4)	Pounds per Acre Totals		
ments	N	P_2O_5*	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
A	50	100	150	50	150	50	0	150	100	300
X	50	100	150	75	150	75	0	200	100	300
B	50	100	150	100	150	100	0	250	100	300
or B	50	100	150	70	150	65	65	250	100	300

* This may be a surface application.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization

Treat-	(1)			(2)	(3)	Pounds per Acre Totals		
ments	N	P_2O_5*	K_2O	N	N	N	P_2O_5	K_2O
A	41	300	150	42	42	125	300	150
X	58	300	150	58	59	175	300	150
B	75	300	150	75	75	225	300	150

* On plant cane this P_2O_5 would go on with the seed; on ratoons it would be put in the subsoil or off-bar furrow.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

NOTE: The numerals in parentheses—(1), (2), (3), (4), (5)—indicate the first, second, third, fourth and fifth applications of fertilizer respectively.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization									Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)		Totals		
ments	N	P_2O_5	K_2O	N	K_2O	N	N		N	P_2O_5	K_2O
A	40	150	125	60	125	0	0		100	150	250
B	40	150	125	60	125	50	0		150	150	250
C	40	150	125	60	125	50	50		200	150	250
D	40	150	125	60	125	75	75		250	150	250

Arrangement: No. 17, 19, or 23.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization									Pounds per Acre		
Treat-	(1)				(2)	(3)	(4)	(5)	Totals		
ments	N	P_2O_5*	K_2O	N	K_2O	N	N	N	N	P_2O_5	K_2O
A	40	200	100	35	100	0	0	0	75	200	200
B	40	200	100	50	100	60	0	0	150	200	200
C	40	200	100	50	100	60	75	0	225	200	200
D	40	200	100	75	100	60	75	50	300	200	200

* On plant cane this 200 pounds could be put in with the seed, and the N and K_2O later (at 4 to 6 weeks).

"A" or "D" may be omitted.

Arrangement: No. 17, 19, or 23.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)—Extra N in second season.

Plan of Fertilization							Pounds per Acre		
Treat-	(1)			(2)	(3)	(4)	Totals		
ments	N	P_2O_5	K_2O	N	N	N	N	P_2O_5	K_2O
X	50	150	150	62	63	0	175	150	150
A	50	150	150	62	63	50	225	150	150

Arrangement: No. 1, 2, 3, 4, or 5.

Kind of Experiment: AMOUNTS OF NITROGEN (AN)

Plan of Fertilization							Pounds per Acre		
Treat-	(1)			(2)	(3)	(4)	Totals		
ments	N	P_2O_5	K_2O	N	N	N*	N	P_2O_5	K_2O
X	30	100	150	30	35	80	175	100	150
A	30	100	150	55	60	80	225	100	150
B	30	100	150	80	85	80	275	100	150

* This second season nitrogen may be applied in two 40-pound applications.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant or ratoons.

Plan of Fertilization							Pounds per Acre		
Treat-	(1)	(2)		(3)		(4)	Totals		
ments	P_2O_5*	N	K_2O	N	K_2O	N†	N	P_2O_5	K_2O
X	0	60	125	60	125	80	200	0	250
A	100	60	125	60	125	80	200	100	250
B	200	60	125	60	125	80	200	200	250
C	400	60	125	60	125	80	200	400	250

* Applied with the seed for plant cane, preferably in the subsoil or off-bar furrow for ratoons if treatment "C" is included. (See note.)

† This N may be split into two 40-pound doses. Treatment "C" may not be necessary or may be at 300 pounds P_2O_5.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant or ratoons.

Plan of Fertilization									Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)		Totals	
ments	N	P_2O_5	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
X	40	0	125	60	125	50	50	200	0	250
A	40	150	125	60	125	50	50	200	150	250
B	40	300	125	60	125	50	50	200	300	250

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For plant cane.

Plan of Fertilization						Pounds per Acre		
Treat-	(1)	(2)		(3)	(4)		Totals	
ments	P_2O_5*	N	K_2O	N	N	N	P_2O_5	K_2O
X	0	50	100	50	75	175	0	100
A	200	50	100	50	75	175	200	100
B	400	50	100	50	75	175	400	100
C	600	50	100	50	75	175	600	100

* Applied with the seed.

Either "B" or "C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For ratoons.

Plan of Fertilization								Pounds per Acre		
Treat-	(1)			(2)		(3)	(4)		Totals	
ments	N	P_2O_5*	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
X	40	0	100	60	100	50	50	200	0	200
A	40	100	100	60	100	50	50	200	100	200
B	40	200	100	60	100	50	50	200	200	200
C	40	300	100	60	100	50	50	200	300	200

* This may be a surface application. "C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF PHOSPHATE (AP)—For low phosphate fixing soils.

Plan of Fertilization									Pounds per Acre		
Treat-	(1)			(2)	(3)			(4)		Totals	
ments	N	P_2O_5	K_2O	N	N	P_2O_5	K_2O	N	N	P_2O_5	K_2O
X	40	0	75	60	60	0	75	65	225	0	150
A	40	50	75	60	60	50	75	65	225	100	150
B	40	100	75	60	60	100	75	65	225	200	150
C	40	150	75	60	60	150	75	65	225	300	150

"B" or "C" may be omitted.

Arrangement: No. 18 or 22.

NOTE: In field experiments, when raw rock phosphate is used, it should be mixed into the soil and not spread upon the surface. When soluble phosphates are used, it may be advisable to avoid much mixing of them with the soil.

In AP and AK tests, the "zero" treatment should not be omitted until or unless there is definite proof that the test area responds to the plant food concerned.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	Totals N	Totals P_2O_5	Totals K_2O
X	40	300	0	60	0	50	50	200	300	0
A	40	300	50	60	50	50	50	200	300	100
B	40	300	100	60	100	50	50	200	300	200
C	40	300	150	60	150	50	50	200	300	300

"C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(3) K_2O	Totals N	Totals P_2O_5	Totals K_2O
X	50	150	0	50	0	75	0	175	150	0
A	50	150	125	50	0	75	0	175	150	125
B	50	150	125	50	125	75	0	175	150	250
C	50	150	125	50	125	75	125	175	150	375

"C" may be omitted.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS OF POTASH (AK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	(5) N	Totals N	Totals P_2O_5	Totals K_2O*
X	30	100	0	70	0	50	50	50	250	100	0
A	30	100	75	70	75	50	50	50	250	100	150
B	30	100	150	70	150	50	50	50	250	100	300

* These totals may be 0-200-400 respectively, with the K_2O to be applied in 2 doses, i.e., 100-100 pounds and 200-200 pounds to "A" and "B" treatments.

Applications 3 and 4, or 4 and 5 may be combined, i.e., at 100 pounds N.

Arrangement: No. 6, 7, 8, 9, 10, 11, 12, 13, 14, or 15.

Kind of Experiment: AMOUNTS OF NITROGEN AND POTASH (ANK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N	(4) K_2O	(5) N	Totals N	Totals P_2O_5	Totals K_2O
A	200	50	125	50	125	50	0	50	200	200	250
B	200	50	125	75	125	75	0	75	275	200	250
C	200	50	125	75	125	75	100	75	275	200	350
D	200	50	125	50	125	50	100	50	200	200	350

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF PHOSPHATE AND POTASH (APK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5*	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N	(4) K_2O	Totals N	Totals P_2O_5	Totals K_2O
A	200	75	125	75	125	75	0	225	200	250
B	600	75	125	75	125	75	0	225	600	250
C	600	75	150	75	200	75	150	225	600	500
D	200	75	150	75	200	75	150	225	200	500

* Applied with seed.

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN AND PHOSPHATE (ANP)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N	(5) N	Totals N	Totals P_2O_5	Totals K_2O
A	200	50	100	50	100	50	50	200	200	200
B	200	50	100	75	100	75	75	275	200	200
C	600	50	100	75	100	75	75	275	600	200
D	600	50	100	50	100	50	50	200	600	200

Arrangement: No. 20, 25 or 19.

Kind of Experiment: AMOUNTS OF NITROGEN, PHOSPHATE AND POTASH (ANPK)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	(4) N	Totals N	Totals P_2O_5	Totals K_2O
A	200	30	150	40	150	40	40	150	200	300
B	200	50	150	50	150	50	50	200	200	300
C	200	50	0	60	0	70	70	250	200	0
D	200	50	75	60	75	70	70	250	200	150
E	0	50	150	60	150	70	70	250	0	300
F	100	50	150	60	150	70	70	250	100	300
X	200	50	150	60	150	70	70	250	200	300

Arrangement: No. 31.

Kind of Experiment: AMOUNTS AND FORMS OF PHOSPHATE (AFP)—For Plant Cane

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5*	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N†	Totals N	Totals P_2O_5	Totals K_2O
X—no P_2O_5	0	60	100	60	100	80	200	0	200
A—superphosphate	200	60	100	60	100	80	200	200	200
B—superphosphate	400	60	100	60	100	80	200	400	200
C—rock phosphate	400	60	100	60	100	80	200	400	200

* Applied with seed.

† May be put on in 2 doses; 40 pounds and 40 pounds.

Arrangement: No. 18 or 22.

Kind of Experiment: AMOUNTS AND FORMS OF PHOSPHATE (AFP)—For Plant Cane Only

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5*	(2) N	(2) K_2O	(3) N	(4) N	Totals N	Totals P_2O_5	Totals K_2O
X—no P_2O_5	0	40	150	80	80	200	0	150
A—superphosphate	150	40	150	80	80	200	150	150
B—rock phosphate	150	40	150	80	80	200	150	150
C—rock phosphate	600	40	150	80	80	200	600	150
D—superphosphate	600	40	150	80	80	200	600	150

* Applied with seed.

Arrangement: No. 27, 28 or 29.

Kind of Experiment: FORMS OF NITROGEN (FN)

Plan of Fertilization							Pounds per Acre		
Treat-		(1)		(2)	(3)	(4)		Totals	
ments	N	P_2O_5	K_2O	N	N	N	N	P_2O_5	K_2O
X—amm. sulp.	30	200	150	35	30	30	125	200	150
A—amm. sulp.	40	200	150	60	60	40	200	200	150
B—nit. soda	40	200	150	60	60	40	200	200	150
C—nit. lime	40	200	150	60	60	40	200	200	150
or C—urea	40	200	150	60	60	40	200	200	150

Either "B" or "C" may be omitted.

Arrangement: For 3 "forms": No. 16, 21 or 24.
For 2 "forms only": No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF PHOSPHATE (FP)

Plan of Fertilization							Pounds per Acre		
Treat-	(1)	(2)		(3)		(4)		Totals	
ments	P_2O_5*	N	K_2O	N	K_2O	N	N	P_2O_5	K_2O
X—no P_2O_5	0	50	125	60	125	65	175	0	250
A—superphos.	200	50	125	60	125	65	175	200	250
B—rock phos.	200	50	125	60	125	65	175	200	250
C—rev. phos.	200	50	125	60	125	65	175	200	250

* Applied with seed.

"C" may or may not be included.

Arrangement: For 3 "*forms*": No. 16, 21 *or* 24.
For 2 "forms only": No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF POTASH (FK)

Plan of Fertilization								Pounds per Acre		
Treat-		(1)		(2)		(3)	(4)		Totals	
ments	N	P_2O_5	K_2O	N	K_2O	N	N	N	P_2O_5	K_2O
X—No K_2O	40	300	0	60	0	60	65	225	300	0
A—Muriate	40	300	150	60	100	60	65	225	300	250
B—Sulp.	40	300	150	60	100	60	65	225	300	250

Arrangement: No. 6, 7, 10, 11, 13 or 15.

Kind of Experiment: FORMS OF NITROGEN AND POTASH (FNK)

Plan of Fertilization									Pounds per Acre
Treat-			(1)				(2)		
ments	Super	A.S.	N.P.	N.S.	M.P.	A.S.	N.P.	N.S.	M.P.
X—Amm. Sulp.+Mur. Pot.	975	100	...	...	155	180	...	...	155
A—Amm. Sulp.+Mur. Pot.	975	146	...	...	155	293	...	...	155
B—Nitrate Potash	975	...	200	...	...	...	400	...	...
C—Nit. Soda+Mur. Pot.	975	...	...	195	155	...	...	385	155

Treat-		(3)			(4)			Totals	
ments	A.S.	N.P.	N.S.	A.S.	N.P.	N.S.	N	P_2O_5	K_2O
X	180	...	...	150	...	...	125	200	186
A	293	...	...	243	...	...	200	200	186
B	...	400	...	...	333	...	200	200	186
C	...	...	385	...	...	325	200	200	186

Analysis: Super at 20.5% P_2O_5.
Nit. Potash at 15% N, 14% K_2O.
Mur. Potash at 60% K_2O.
Amm. Sulp. at 20.5% N.
Nit. Soda at 15.5% N.

Arrangement: No. 16, 21, or 24.

Kind of Experiment: TIME TO APPLY NITROGEN (TN)

Plan of Fertilization

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	(4) N	(5) N	Pounds per Acre Totals N	P_2O_5	K_2O
	First Season					Second Season				
X	40	150	150	0	40	0	40	120	150	150
A	40	150	150	40	40	40	40	200	150	150
B	120	150	150	0	0	40	40	200	150	150
C	40	150	150	80	0	80	0	200	150	150
D	40	150	150	80	0	40	40	200	150	150

"D" may or may not be included.

Arrangement: With treatment "D" included—No. 27, 28 or 29.
Without treatment "D"—No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY PHOSPHATE (TP)

Plan of Fertilization

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) P_2O_5	(3) N	(3) P_2O_5	Pounds per Acre Totals N	P_2O_5	K_2O
A	50	200	100	60	0	65	0	175	200	100
B	50	100	100	60	0	65	100	175	200	100
C	50	70	100	60	65	65	65	175	200	100
X	50	0	100	60	0	65	0	175	0	100

Arrangement: No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY POTASH (TK)

Plan of Fertilization

Treat-ments	(1) N	(1) P_2O_5*	(1) K_2O	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N	(4) K_2O	Pounds per Acre Totals N	P_2O_5	K_2O
A	40	200	200	60	0	60	0	40	0	200	200	200
B	40	200	100	60	100	60	0	40	0	200	200	200
C	40	200	50	60	50	60	50	40	50	200	200	200
X	40	200	0	60	0	60	0	40	0	200	200	0

* This P_2O_5 may be put on before the N and K_2O.

Arrangement: No. 16, 21 or 24.

Kind of Experiment: TIME TO APPLY PHOSPHATE AND POTASH (TPK)

Plan of Fertilization

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) P_2O_5	(2) K_2O	(3) N	(3) P_2O_5	(3) K_2O	(4) N	(4) P_2O_5	(4) K_2O
A	40	200	250	60	0	0	60	0	0	40	0	0
B	40	200	62	60	0	63	60	0	63	40	0	62
C	40	200	0	60	0	150	60	0	0	40	0	100
D	40	100	0	60	0	150	60	100	0	40	0	100
E	40	50	0	60	50	150	60	50	0	40	50	100
X	40	0	0	60	0	125	60	0	0	40	0	125
Y	40	100	0	60	0	0	60	100	0	40	0	0

Treat-ments	Pounds per Acre Totals N	P_2O_5	K_2O
A	200	200	250
B	200	200	250
C	200	200	250
D	200	200	250
E	200	200	250
X	200	0	250
Y	200	200	0

Arrangement: No. 31.

Kind of Experiment: AMM. PHOS. + AMM. SULPH. VS. SUPERPHOS. + AMM. SULPH. (X)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) P_2O_5	(3) N	Totals N	Totals P_2O_5	Totals K_2O
X—No P_2O_5	50	0	150	60	0	65	175	0	150
A—Ammophos.	50	125	150	60	75	65	175	200	150
B—Superphos.	50	125	150	60	75	65	175	200	150

Arrangement: No. 6, 7, 10, 11 or 15.

Kind of Experiment: NITRATE OF POTASH VS. AMM. SULPH. + MUR. POTASH (X)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) P_2O_5	(2) N	(2) K_2O	(3) N	(3) K_2O	(4) N	(4) K_2O	Totals N	Totals P_2O_5	Totals K_2O
A—Amm. Sulp. & Mur.	150	50	47	80	74	0	47	130	150	168
B—Amm. Sulp. & Mur.	150	50	47	80	74	50	47	180	150	168
C—Nitrate Potash	150	50	47	80	74	50	47	180	150	168
D—Nitrate Soda	150	50	0	80	0	50	0	180	150	0

Arrangement: No. 17, 19 or 23.

Kind of Experiment: METHOD OF APPLICATION (X)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) Amm. Phos.	Muriate	(2) Amm. Sul.	(3) Amm. Sul.	(4) Amm. Sul.	Totals N	Totals P_2O_5	Totals K_2O
A—By hand	300	150	300	300	200	194	144	90
X—By water	300	150	300	300	200	194	144	90

Arrangement: No. 1, 2, 3, 4 or 5.

Kind of Experiment: PLACEMENT OF FERTILIZER (X)

Plan of Fertilization — Pounds per Acre

Treat-ments	(1) Amm. Sul.	(2) "P-2" Hi-Grade*	(3) Amm. Sul.	Totals N	Totals P_2O_5	Totals K_2O
A—In the cane line	400	416	400	206	80	80
B—In the row middle	400	416	400	206	80	80
X—In the cane line	300	416	300	163	80	80

* Analysis of "P-2"=9.6 per cent N, 19.2 per cent P_2O_5, 19.2 per cent K_2O. (This may be any "Hi-Grade".)

Arrangement: No. 8, 9, 12, 13 or 14.

Kind of Experiment: LIME (L)

Plan of Fertilization — Pounds per Acre

Treat-ments	Tons Lime	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(2) K_2O	(3) N	Totals N	Totals P_2O_5	Totals K_2O
X—No Lime	0	40	300	125	60	125	75	175	300	250
A—Lime (1)	2½	40	300	125	60	125	75	175	300	250
B—Lime (1)	5	40	300	125	60	125	75	175	300	250
C—Lime (2)	2½	40	300	125	60	125	75	175	300	250

(1) Harrowed in before furrowing.

(2) Mixed in the furrow before planting.

Arrangement: No. 18 or 22.

Kind of Experiment: AGE OF HARVEST (AH)

Plan of Fertilization

Treatments	(1) N	(1) P_2O_5	(1) K_2O	(2) N	(3) N	Pounds per Acre Totals N	P_2O_5	K_2O
A—Harvest at 12 mos.	50	100	150	60	70	180	100	150
B—Harvest at 15 or 16 mos.	50	100	150	60	70	180	100	150
C—Harvest at 18 or 20 mos.	50	100	150	60	70	180	100	150
D—Harvest at 21 or 24 mos.	50	100	150	60	70	180	100	150

Arrangement: No. 26.

Kind of Experiment: CULTIVATION (C)

Plan of Fertilization

Treatments	(1) P_2O_5	(2) N	(2) K_2O	(3) N	(4) N	Pounds per Acre Totals N	P_2O_5	K_2O
A—Subsoiled	150	50	100	60	75	185	150	100
X—Not subsoiled	150	50	100	60	75	185	150	100

Arrangement: No. 1, 2, 3, 4 or 5.

Kind of Experiment: VALUE OF N AND K_2O IN MOLASSES (M)

Plan of Fertilization

Treatments	(1) Molasses	(2) N	(2) P_2O_5	(2) K_2O	(3) N	(4) N	(5) N	Pounds per Acre Totals N	P_5O_5	K_2O
A	0 tons	50	250	400	0	60	50	160	250	400
B	5	50	250	0	0	60	50	210	250	460
C	0	50	250	0	50	60	50	210	250	0
D	0	50	250	400	50	60	50	210	250	400

Molasses analyses assumed at .5 per cent N and 4.0 per cent K_2O, or 10 pounds N and 80 pounds K_2O per ton: therefore 50 pounds N and 400 pounds K_2O from 5 tons molasses used on treatment "B."

The fifth application of fertilizer (nitrogen) may or may not be needed.

Arrangement: No. 20, 25 or 19.

Kind of Experiment: VALUE OF N AND P_2O_5 IN PRESS CAKE (X)

Plan of Fertilization

Treatments	(1) Fresh press cake	(2) N	(2) P_2O_5*	(2) K_2O	(3) N	(3) K_2O	(4) N	(5) N	Pounds per Acre Totals N	P_2O_5	K_2O
A	0 tons	50	346	150	0	150	76	?	126	346	300
B	10	50	0	150	0	150	0	?	176	346	300
C	0	50	0	150	50	150	76	?	176	0	300
D	0	50	346	150	50	150	76	?	176	346	300

Fresh press cake analyses assumed at 73 per cent water, .63 per cent N, 1.73 per cent P_2O_5, or 12.6 pounds N and 34.6 pounds P_2O_5 per ton of fresh cake.

A fifth application of fertilizer (nitrogen only) may be applied similarly to all treatments.

* This P_2O_5 to be applied as superphosphate.

Arrangement: No. 20, 25 or 19.

Approved "Arrangements of Treatments"

for "Grade A" experiments with fertilizers, cultural practices, etc.

I.- For Two Treatments

a.- Plots in two columns

No. 1. Preferred (1) arrangement

c.c.	1 X	2 A	3 A	4 X	5 X	6 A	7 A	8 X	9 X	10 A	c.c.
c.c.	11 A	12 X	13 X	14 A	15 A	16 X	17 X	18 A	19 A	20 X	c.c.

No. 2 Alternate (1) Arrangement.

c.c.	1 X	2 A	3 X	4 A	5 X	6 A	7 X	8 A	9 X	10 A	c.c.
c.c.	11 A	12 X	13 A	14 X	15 A	16 X	17 A	18 X	19 A	20 X	c.c.

b.- Plots in three columns

No. 3 Preferred (1)

c.c.	1 X	2 A	3 A	4 X	5 X	6 A	7 A	8 X	c.c.
c.c.	9 A	10 X	11 X	12 A	13 A	14 X	c.c.		
c.c.	15 X 15	16 A	17 A	18 X	19 X	20 A	c.c.		

No. 4 Alternate (1)

c.c.	1 X	2 A	3 X	4 A	5 X	6 A	7 X	8 A	c.c.
c.c.	9 A	10 X	11 A	12 X	13 A	14 X	c.c.		
c.c.	15 X	16 A	17 X	18 A	19 X	20 A	c.c.		

c.- Strip Experiment. (1)

No. 5

c.c.	c.c.	c.c.	c.c.	c.c.
1 X	5 X	9 X	13 X	17 X
2 A	6 A	10 A	14 A	18 A
3 A	7 A	11 A	15 A	19 A
4 X	8 X	12 X	16 X	20 X
c.c.	c.c.	c.c	c.c	c.c.

"Strip" experiments should be duplicated or triplicated in other parts of the field. Each strip may be divided into several unit plots for harvest data.

Legend used:

A-B-C-D-E-F-X-Y-etc. designate respective treatments of plots as numbered.
C.C.- Crop cane
(1) for "Student's" method of analysis
(2) for Fisher's "Analysis of Variance"
(3) for either "Student's" or the "Analysis of Variance"
(4) for experiments that do not need a "control" treatment.

II.— For Three Treatments

a.- Plots in two columns (where border effect between treatments is not expected to be pronounced, or where border rows will be discarded at harvest.)

No. 6

Preferred: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	13 A	14 X	15 B	c.c.
c.c.	16 B	17 X	18 A	19 B	20 X	21 A	22 B	23 X	24 A	25 B	26 X	27 A	28 B	29 X	30 A	c.c.

No. 7

Alternate: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	13 A	14 X	15 B	c.c.
c.c.	16 X	17 B	18 A	19 X	20 B	21 A	22 X	23 B	24 A	25 X	26 B	27 A	28 X	29 B	30 A	c.c.

b.- Plots in two columns (where border effect is expected to be pronounced, or where border rows are not to be discarded at harvest.)

No. 8

Preferred: (1)

c.c.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	11 X	12 B	13 B	14 X	15 X	16 A	17 A	18 X	19 X	20 B	c.c.
c.c.	21 B	22 X	23 X	24 A	25 A	26 X	27 X	28 B	29 B	30 X	31 X	32 A	33 A	34 X	35 X	36 B	37 B	38 X	39 X	40 A	c.c.

No. 9

Preferred: (2)

c.c.	1 A	2 X	3 B	4 B	5 X	6 A	7 A	8 X	9 B	10 B	11 X	12 A	13 A	14 X	15 B	c.c.
c.c.	16 B	17 X	18 A	19 A	20 X	21 B	22 B	23 X	24 A	25 A	26 X	27 B	28 B	29 X	30 A	c.c.

c.- Plots in three columns (with no border effect expected, or where border rows will be discarded at harvest.)

No. 10

Preferred: (3)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	12 B	c.c.
c.c.	13 B	14 X	15 A	16 B	17 X	18 A	19 B	20 X	21 A	22 B	23 X	24 A	c.c.
c.c.	25 A	26 X	27 B	28 A	29 X	30 B	c.c.						

No. 11

Alternate: (1)

c.c.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	10 A	11 X	c.c.
c.c.	12 X	13 B	14 A	15 X	16 B	17 A	18 X	19 B	20 A	21 X	22 B	c.c.
c.c.	23 A	24 X	25 B	26 A	27 X	28 B	29 A	30 X	31 B	c.c.		

d. – Plots in three columns (with expected border effect or where border rows will not be discarded at harvest.)

No. 12

Preferred: (1)

C.C.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	11 X	12 B	13 B	14 X	C.C.
C.C.	15 B	16 X	17 X	18 A	19 A	20 X	21 X	22 B	23 B	24 X	25 X	26 A	27 A	28 X	C.C.
C.C.	29 A	30 X	31 X	32 B	33 B	34 X	35 X	36 A	37 A	38 X	39 X	40 B	41 B	42 X	C.C.

No. 13

Preferred: (2)

C.C.	1 A	2 X	3 B	4 B	5 X	6 A	7 A	8 X	9 B	10 B	11 X	12 A	C.C.
C.C.	13 B	14 X	15 A	16 A	17 X	18 B	19 B	20 X	21 A	22 A	23 X	24 B	C.C.
C.C.	25 A	26 X	27 B	28 B	29 X	30 A	C.C.						

e. – Plots in four columns (with expected border effect.)

No. 14

Preferred: (1)

C.C.	1 A	2 X	3 X	4 B	5 B	6 X	7 X	8 A	9 A	10 X	C.C.
C.C.	11 X	12 B	13 B	14 X	15 X	16 A	17 A	18 X	19 X	20 B	C.C.
C.C.	21 B	22 X	23 X	24 A	25 A	26 X	27 X	28 B	29 B	30 X	C.C.
C.C.	31 X	32 A	33 A	34 X	35 X	36 B	37 B	38 X	39 X	40 A	C.C.

f. – Plots in four columns (with no border effect expected.)

No. 15

Preferred: (3)

C.C.	1 A	2 X	3 B	4 A	5 X	6 B	7 A	8 X	9 B	C.C.
C.C.	10 B	11 X	12 A	13 B	14 X	15 A	16 B	17 X	18 A	C.C.
C.C.	19 A	20 X	21 B	22 A	23 X	24 B	C.C.			
C.C.	25 B	26 X	27 A	28 B	29 X	30 A	C.C.			

III – For Four Treatments

a.– Plots in two columns (where border effect is not expected to be pronounced.)

No. 16

Preferred: (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	12 B	13 X	14 C	15 A	16 X	17 B	18 C	19 X	20 A	21 B	22 X	23 C	C.C.
C.C.	24 B	25 X	26 C	27 A	28 X	29 B	30 C	31 X	32 A	33 B	34 X	35 C	36 A	37 X	38 B	39 C	40 X	41 A	42 B	43 X	44 C	45 A	46 X	C.C.

(Where border effect is expected)

No. 17

Preferred: (1) (4)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	17 A	18 B	19 C	20 D	C.C.
C.C.	21 D	22 C	23 B	24 A	25 A	26 B	27 C	28 D	29 D	30 C	31 B	32 A	33 A	34 B	35 C	36 D	37 D	38 C	39 B	40 A	C.C.

b.– Plots in three columns (where border effect is expected)

No. 18

Preferred: (3)

C.C.	1 X	2 A	3 B	4 C	5 C	6 B	7 A	8 X	9 X	10 A	11 B	12 C	13 C	14 B	15 A	16 X	C.C.
C.C.	17 C	18 B	19 A	20 X	21 X	22 A	23 B	24 C	25 C	26 B	27 A	28 X	29 X	30 A	31 B	32 C	C.C.
C.C.	33 X	34 A	35 B	36 C	37 C	38 B	39 A	40 X	C.C.								

No. 19

Preferred: (2) (4)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	C.C.
C.C.	17 D	18 C	19 B	20 A	21 A	22 B	23 C	24 D	25 D	26 C	27 B	28 A	29 A	30 B	31 C	32 D	C.C.
C.C.	33 A	34 B	35 C	36 D	37 D	38 C	39 B	40 A	C.C.								

c.– Plots in three columns (where border effect is not expected.)

No. 20

Preferred: (1)

C.C.	1 A	2 B	3 C	4 D	5 A	6 B	7 C	8 D	9 A	10 B	11 C	12 D	13 A	14 B	15 C	16 D	17 A	C.C.
C.C.	18 D	19 C	20 B	21 A	22 D	23 C	24 B	25 A	26 D	27 C	28 B	29 A	30 D	31 C	32 B	33 A	34 D	C.C.
C.C.	35 A	36 B	37 C	38 D	39 A	40 B	41 C	42 D	43 A	C.C.								

No. 21

Preferred: (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	12 B	13 X	14 C	15 A	16 X	C.C.
C.C.	17 B	18 X	19 A	20 C	21 X	22 B	23 A	24 X	25 C	26 B	27 X	28 A	29 C	30 X	31 B	C.C.	
C.C.	32 C	33 X	34 A	35 B	36 X	37 C	38 A	39 X	40 B	41 C	42 X	43 A	44 B	45 X	46 C	C.C.	

d.- Plots in four columns (where border effect is expected)

No. 22

Preferred : (3)

C.C.	1 X	2 A	3 B	4 C	5 C	6 B	7 A	8 X	9 X	10 A	11 B	12 C	C.C.
C.C.	13 C	14 B	15 A	16 X	17 X	18 A	19 B	20 C	21 C	22 B	23 A	24 X	C.C.
C.C.	25 X	26 A	27 B	28 C	29 C	30 B	31 A	32 X	C.C.				
C.C.	33 C	34 B	35 A	36 X	37 X	38 A	39 B	40 C	C.C.				

No. 23

Preferred : (2)

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	9 A	10 B	11 C	12 D	C.C.
C.C.	13 D	14 C	15 B	16 A	17 A	18 B	19 C	20 D	21 D	22 C	23 B	24 A	C.C.
C.C.	25 A	26 B	27 C	28 D	29 D	30 C	31 B	32 A	C.C.				
C.C.	33 D	34 C	35 B	36 A	37 A	38 B	39 C	40 D	C.C.				

e.- Plots in four columns (where border effect is not expected)

No. 24

Preferred : (1)

C.C.	1 X	2 A	3 B	4 X	5 C	6 A	7 X	8 B	9 C	10 X	11 A	C.C.	
C.C.	12 B	13 X	14 C	15 A	16 X	17 B	18 C	19 X	20 A	21 B	22 X	23 C	C.C.
C.C.	24 X	25 C	26 A	27 X	28 B	29 C	30 X	31 A	32 B	33 X	34 C	C.C.	
C.C.	35 A	36 X	37 B	38 C	39 X	40 A	41 B	42 X	43 C	44 A	45 X	46 B	C.C.

No. 25

Preferred : (1) (4)

C.C.	1 A	2 B	3 C	4 D	5 A	6 B	7 C	8 D	9 A	10 B	11 C	C.C.
C.C.	12 B	13 A	14 D	15 C	16 B	17 A	18 D	19 C	20 B	21 A	22 D	C.C.
C.C.	23 C	24 D	25 A	26 B	27 C	28 D	29 A	30 B	31 C	32 D	33 A	C.C.
C.C.	34 D	35 C	36 B	37 A	38 D	39 C	40 B	41 A	42 D	43 C	44 B	C.C.

f.- Special arrangement of four treatments

No. 26

(1) Preferred

C.C.	1 A	2 B	3 C	4 D	5 D	6 C	7 B	8 A	C.C.
C.C.	9 A	10 B	11 C	12 D	13 D	14 C	15 B	16 A	C.C.
C.C.	17 A	18 B	19 C	20 D	21 D	22 C	23 B	24 A	C.C.
C.C.	25 D	26 C	27 B	28 A	29 A	30 B	31 C	32 D	C.C.
C.C.	33 D	34 C	35 B	36 A	37 A	38 B	39 C	40 D	C.C.
C.C.	41 D	42 C	43 B	44 A	45 A	46 B	47 C	48 D	C.C.

IV.- For Five Treatments

a.- A control plot as every third plot:

No. 27

Preferred: (1)

C.C.	A	X	B	C	X	D	A	X	B	C	X	D	A	X	B	C	etc.
C.C.	X	A	D	X	C	B	X	A	D	X	C	B	X	A	etc.		
C.C.	A	X	B	C	etc.												
C.C.	etc.																

b.- Two Latin Squares

No. 28

Preferred: (2)

C.C.	1 X	2 A	3 B	4 C	5 D	6 B	7 A	8 X	9 D	10 C	C.C.
C.C.	11 B	12 C	13 D	14 X	15 A	16 D	17 C	18 B	19 A	20 X	C.C.
C.C.	21 D	22 X	23 A	24 B	25 C	26 A	27 X	28 D	29 C	30 B	C.C.
C.C.	31 A	32 B	33 C	34 D	35 X	36 C	37 B	38 A	39 X	40 D	C.C.
C.C.	41 C	42 D	43 X	44 A	45 B	46 X	47 D	48 C	49 B	50 A	C.C.

c.- Balanced Blocks

No. 29

Preferred: (2)

C.C.	X	A	B	C	D	D	C	B	A	X	X	A	B	C	D	etc.
C.C.	D	C	B	A	X	X	A	B	C	D	etc.					
C.C.	X	A	B	C	D	etc.										
C.C.	etc.															

d.- Duplicate plots adjacent (where border effect is expected)

No. 30

Preferred: (1)
(4)

C.C.	A	B	B	C	C	D	D	E	E	D	D	C	C	B	B	A	C.C.
C.C.	B	C	C	D	D	E	E	D	D	C	C	B	B	A	A	B	C.C.
C.C.	C	D	D	E	E	D	D	C	C	B	B	etc.					
C.C.	D	E	E	etc.													
C.C.	etc.																

V.– For Six Treatments

a. – Use a control plot as every third plot.

b. – Use two 6 X 6 Latin Squares.

c. – Use Balanced Blocks.

VI.– For Seven (or more) Treatments

a. – Use a control plot as every third plot.

b. – Use Balanced Blocks

c. – Use a single 7 X 7 Latin Square for 7 treatments; on 8 X 8 for 8 treatments; etc.

No. 31

Preferred (2)

C.C.	1 A	2 B	3 C	4 D	5 E	6 X	7 Y	C.C.
C.C.	8 D	9 E	10 X	11 Y	12 A	13 B	14 C	C.C.
C.C.	15 Y	16 A	17 B	18 C	19 D	20 E	21 X	C.C.
C.C.	22 B	23 C	24 D	25 E	26 X	27 Y	28 A	C.C.
C.C.	29 E	30 X	31 Y	32 A	33 B	34 C	35 D	C.C.
C.C.	36 C	37 D	38 E	39 X	40 Y	41 A	42 B	C.C.
C.C.	43 X	44 Y	45 A	46 B	47 C	48 D	49 E	C.C.

A Required Standard for "Grade A" Experiments

The following *minimum* requirements for "Grade A" field experiments are hereby presented:

1. The *object* of a "Grade A" field experiment shall be one that shall have probable application to an adequately large area of land. It must have the possibility of an economic gain or the detection of loss, or contribute reliable data to either an accredited research project or for a probable research study. It shall be concerned with a problem that is adaptable to field testing.

2. The *plan* for a "Grade A" expeiiment shall be one that is designed to give reliable quantitative information on the question that is asked of the cane crop. It shall be of such a nature that we can hope to measure the expected differences between treatments with confidence that the differences found are due to the treatment applied and not to chance alone. Large single applications of soluble nitrogen and potash fertilizers will be avoided, and all unchecked variables and other complicated issues will be considered undesirable. The plan must be approved by the Departments of Agriculture and Genetics, of the Experiment Station, before it is installed.

3. The introduced variables or *treatments* may be of any number, providing: (a) they allow of direct adjacent plot-to-plot comparisons, (b) that they are each located adjacent to plots having a common basic control or check treatment, or (c) that they are suitably arranged in blocks, when visible variations *within* such blocks are not evident.

4. The *area* chosen for the field experiment shall be truly representative of the larger area to which its results will have application. Convenience will be a secondary consideration. (A good check on the representativeness is afforded when two or more tests in the same field are given a common treatment.)

5. The experiment *design* and *layout* shall be of such a nature as to reduce the experimental error and to allow a valid estimate of this error when interpreting the results.

(a) Plot *size* is a matter of practical convenience, but there shall be a minimum size of 1/20 acre. No plot shall consist of less than six lines of cane and harvest data should be secured from not less than the four center cane lines of each plot.

(b) The number of *replications* depends on the size of the experimental error, the precision required, or the size of the differences which we are expecting to measure. The following minimum* requirements are presented:

For variety tests:	5 pairs or comparisons for harvest
For fertilizer tests:	7 pairs or comparisons for harvest
For other tests:	7 pairs or comparisons for harvest

(It is recommended that 10 replications or more be installed.)

*** The design of an experiment depends to a large extent upon the information sought. When a fine issue needs to be settled where the differences in yield between treatments might be expected to be small, a larger number of comparisons are needed than when a grosser issue is under consideration.**

(c) The arrangement of plots shall be such that each treatment will have a similar amount of exposure on roads, trails, track lines, ditches, etc.; guard rows of crop cane are recommended where this exposure cannot be made equal.

6. *Plot areas* for new experiments shall be accurately measured and recorded.

7. *Cultural operations* on all plots shall be uniform (except for those differentials that are being tested). Errors which can influence the results will necessitate the discarding of plots so affected and may thereby automatically remove the experiment from its "Grade A" to a "Grade B" or non-accredited status. Such errors may be: (a) failure to maintain a good stand of cane, (b) accidental burns affecting plots unequally, (c) animal damage, (d) cutting seed before harvest data are obtained, etc.

8. *Harvesting operations* shall be carried on in such a way that accurate cane yields from each plot will be secured.

(a) It is recommended, but not required, that the two outside rows in all 6- or 8-line plots be discarded at harvest; where there are 10 or more lines per plot, these outside lines may, however, be included.

(b) With heavy-tonnage cane, where the cane sticks are so tangled at the borders of the plot that the errors of separation are apt to be large, it is recommended that the cane be carefully separated on the border *prior* to cutting the rest of the plot.

(c) Where cane is weighed in the field, either all the bundles on each plot shall be weighed or gross plot weights shall be calculated from an average bundle weight that shall be obtained by weighing not less than 40 regular field bundles, systematically selected on each plot. An average tare for each plot shall be determined from the gross and net (cleaned) weights of at least six average bundles per 1/20 acre plot, taken at random from scattered points. (Each cutter should be represented by the bundles tared.) Plot yields shall be recorded as net clean cane weights.

9. *Cane sampling* for juice analysis should be resorted to only when it is impossible to crush all of the cane harvested separately for each plot.

(a) Wherever possible all cane grown on each plot shall be crushed separately, in order that analyses of individual plot crusher juices be made therefrom.

(b) Where it is impossible to maintain individual plot identities through the crusher, the cane sampling shall be considered reliable only when each treatment is adequately sampled at least three or four times.

(It is extremely desirable that flumed cane samples consist of cleaned cane only.)

10. The *collection* of the *juice sample* shall be of such a nature that every part of the cane sample crushed shall have an equal chance of being represented in the juice sample that goes to the laboratory for chemical analysis.

Departments of Agriculture and Genetics.

Potash Occurring in Irrigation Water in Relation to Plant Fertilization

By Francis E. Hance, Q. H. Yuen, E. K. Hamamura, T. Nishimura and Paul E. Chu.

Foreword

Sixty-five per cent of Hawaii's sugar crop is grown under irrigated conditions. It has been estimated that a half-million gallons of irrigation water are required per ton of sugar produced. Approximately 325,000 million gallons of water are applied to Hawaiian sugar lands for each crop. All irrigation waters carry salts in variable amounts; in most of them sodium chloride (common salt) predominates. Some pump waters carrying in excess of 100 grains of salt per gallon are found entirely satisfactory as an irrigation supply. Potable water seldom contains more than 25 or 30 grains of salt per gallon. As an illustration of the enormous tonnage of salt involved in the irrigation of sugar cane we cite an hypothetical case. Were it possible for the entire Hawaiian irrigated cane area to employ a water containing as little as 12 grains of sodium chloride per gallon, a water superior to the usual municipal supply, then, as much as 270,000 tons of salt would be carried with it to the cane lands during the period required for a single crop to reach maturity.

Mountain streams may carry as little as 8 pounds of potash per million gallons. Rarely have we found in these waters a concentration exceeding 60 pounds K_2O per million gallons. Waters from artesian basins, however, contain considerably greater quantities of salts, including potash. In general the chlorides of sodium, calcium and magnesium dominate. A survey of analyses of irrigation waters made by the Chemistry Department over a period of several years shows potash to vary between 18 and 507 pounds K_2O per million gallons of water. Maui pump waters are generally richer in potash than are those of the other Islands.

A large portion of the water required for cane irrigation is lifted from underground basins. Operating from artesian wells at maximum capacity, pumps of three plantations on Oahu deliver a total of 270 million gallons of water per 24 hours.

Amounts of Potash Applied by Irrigation Waters Per Cane Crop Cycle:

The volume of water used per crop in the irrigation of Hawaiian cane lands and the tonnage of sodium and potassium salts thus carried to these areas run into figures of astounding magnitude. Assuming an irrigation requirement of 3 million gallons of water per long crop, Hawaiian waters pumped from wells carry to an acre of land amounts of potash varying from 53 to 1,521 pounds of K_2O. The concentration of potash is dependent entirely upon the source from which the water originates. It is within the limits of probability to expect that the potash thus furnished may function to some extent in plant nutrition. Field experiments with varying amounts of potash applied as fertilizer upon irrigated plantations not infrequently show negative response. This finding may be traceable to the

use of irrigation waters naturally high in potash. To illustrate: In a potash fertilization test conducted in a field of a plantation situated on Maui, the 1932 harvest results showed no responsive gain from applications of K_2O up to 280 pounds per acre. Upon investigation it developed that the irrigation water used in this field contained 21 parts per million potash as K_2O. Now, assuming an application of 3 million gallons of water per acre for the crop harvested, 525 pounds of K_2O had been supplied to this field by the water alone.

Soil moisture relationships as affected by irrigation have been made the subject of voluminous research. The rôle of irrigation with respect to changes in the physical state of soils as a result of chemical reactions has likewise been studied by workers both here and abroad. Illustrative of this latter phase of the subject is the very important matter of reclamation of soils by methods involving base replacement.

A subject which has received scant attention until recently is that of the possible utilization by the crop of nutrients contained in irrigation waters.

The concentration of potassium salts in Hawaiian irrigation waters appears very small when expressed in terms of normality or in grams of nutrient per unit volume of water. However, the utilization of this nutrient by the crop even in the great dilution in which it occurs, will be suggested later as not only probable but in addition entirely feasible.

The Nutrient Value of Potash in the Irrigation Supply:

A search of the literature reveals very little pertaining directly to the studies described in these pages or to any research of a similar nature. Nevertheless, from his analyses of irrigation waters of the intermountain region of Utah, having a potassium concentration varying from 0.79 to 59 parts per million, Graves (10) calculated that for an irrigation of 2 acre-feet, 4.4 to 266.6 pounds of the element potassium would have been carried to an acre of soil. Graves recognized the economic significance of his findings after having calculated that the highest amount of potassium found would be sufficient to account for 370 bushels of corn, 230 bushels of wheat, or 34 tons of sugar beets.

Growing Sudan grass in pot experiments with potash as the limiting factor, Verret (32) reported obtaining a slight response to this nutrient when supplied from well water of high potash concentration.

Hester (16) in Virginia, found that the flooding of an area with sea water resulted in a measurable increase in replaceable potassium. Page and Williams (28) observed similar effects from ocean inundation upon English soils.

In the attempted rejuvenation of fields which had been under long and continuous cultivation a flood-fallowing system was used in the British Guiana cane areas. An astonishing increase in yields was obtained as a result of the treatment as compared with similar areas not so handled. Commenting on this, Crabtree (5) mentioned that some workers ascribed the beneficial results to the chemical characteristics of waters used. One plant food found in these waters was nitrogen. The amount was reported as 1.5 parts per million. Granting the whole of the nitrogen to have been utilized by the crop, the total amount added for each acre-foot of water employed would have been but 4 pounds per acre. Crabtree reasoned that this

small amount of nutrient could scarcely account for the total crop increases obtained by flooding, but unfortunately he made no observations regarding potash.

From the study of a fallowed area, neither irrigated nor planted to cane nor fertilized with potash salts, as compared with the soil of an adjacent field having been regularly fertilized, irrigated and cropped intermittently for years, one of us (12) found that the two adjoining areas carried similar concentrations of replaceable potash and practically identical amounts of total potash. Since the many successive harvests of cane must have removed from the cropped field considerably more potash than had been applied as fertilizer, this finding gave support to the probability that potash contained in the irrigation water had made up the amount removed by the crop.

Saline Irrigation in Reference to Accumulations of Sodium Chloride in the Five-Foot Soil Profile:

Gow (11) found evidences which indicated that irrigation water carrying a relatively high concentration of sodium salts over comparatively negligible amounts of potassium salts, did not bring about replacement of potassium by sodium in the soil to any appreciable extent. In a study by one of us in cooperation with H. A. Wadsworth, University of Hawaii, soil specimens were collected from a shaft at successive 6-inch intervals downward for a distance of 5 feet. Study of these specimens by Gow (11) showed that the highest concentration of replaceable potash occurred in the upper 6 inches of soil and that the concentration of this nutrient gradually decreased as the lower levels of the excavation were reached. Although about 25 tons of sodium chloride per acre per year had been applied to this area during 20 years of saline irrigation, determination of water soluble and replaceable sodium gave results which indicated that no accumulation of common salt had occurred anywhere within the five-foot profile region.

Replacement Effect of Sodium Salts Upon Soil Calcium and Potassium:

In an earlier soil study by C. F. Eckart (6), lysimeters, fertilized and unfertilized, were irrigated with water containing 200 grains of common salt per gallon of water. The small-scale irrigation was planned in simulation of plantation practice where salt-bearing well water was employed. In addition to the saline treatments other portions of untreated soil were included in the study whereon only fresh water was employed for irrigation. Hartung and one of us (14) in an interpretation of the results of this experiment in the light of knowledge of base exchange, found evidences to support the belief that the sodium introduced had replaced calcium in the soil complex. The replacement effect upon soil potash was also noted.

Irrigation Water as a Nutrient Solution:

Irrigation water having a high concentration of salts may be considered as potentially a nutrient solution. The relation between concentrations of potassium in culture solutions and optimum plant growth has been studied, among others, by Bartholomew and Janssen (2), Parker and Pierre (29) and Johnston and Hoagland

(19). The results obtained by the workers cited indicate that the minimum concentration of potassium requisite for plant growth lies within the range of 2 to 5 parts of potassium per million parts of culture solution. This would be equivalent to irrigation waters carrying respectively 20 pounds and 50 pounds of potash as K_2O per million gallons of water, a concentration *less* than the average for many Hawaiian artesian waters. Artesian waters of Maui contain on an average about 165 pounds K_2O per million gallons, while those of Oahu average about 40 pounds per million gallons. Thus it becomes apparent that any of these irrigation waters could be used as a flowing culture solution without the addition of potash, it being necessary only to supplement it with other nutrients.

In support of this hypothesis we cite the work of H. L. Lyon and H. Brodie (22) who found that H 109 cane could be grown in a culture solution consisting purely of running tap water. This was accomplished when the plant was started from an immature cane stalk of fair length. Thus far cane started from small cuttings or shoots has not developed plants of normal growth in Honolulu tap water. The question, therefore, of the degree of dilution from which cane so started can take nutrition is an open one and offers an interesting subject for future study.

Relationships Between Exchangeable Potash and Crop Response:

Other investigators have shown that plants can utilize potash from the exchange complex. In studying California soils in iron containers wherein barley was cropped continually for 12 years, Martin (24) found that replaceable potassium showed a marked decrease as the result of the cropping. Wilson (34), working with New York State soils, observed similar results in his study of exchangeable calcium and potassium as affected by cropping and fertilization. Relationships between replaceable soil potash and crop production have been reported by other investigators, including Nostitz (27), Breazeale (4), Kelley (20), Hissink (17), Gedroiz (9), Hoagland and Martin (18). Fraps (8), and McCool and Weldon (25) showed that the potassium content of plants was, in general, dependent upon the "available" potassium in the soil. Magistad (23) in field experiments with pineapples, found a marked relationship between the concentration of replaceable potassium in Hawaiian soils and response to potash fertilization.

The Role of Non-Exchangeable Soil Potash in Plant Absorption:

While the relationship of replaceable potash to plant growth is undoubtedly of great importance the role of the non-exchangeable fraction is not without significance. After a practically complete replacement of magnesium and potassium from a Russian soil, Gedroiz (9) found that certain plants were not only able to develop in such an environment but actually produced a more or less normal yield. The plants so grown apparently obtained these elements in amounts sufficient for their needs and hence by inference (provided seed or other introduction did not supply them) were able to utilize the unexchangeable fractions of magnesium and potassium which were originally present in the soil.

The Function of Sodium in Plant Nutrition:

Due to the marked similarity in chemical properties of sodium and potassium, and to the presence of large concentrations of common salt in saline irrigation waters, a brief consideration of the rôle of sodium in plant nutrition may be of interest. Many investigators are of the opinion that sodium cannot replace potassium in plant processes. Hartwell and Pember (15) concluded from their experiments with Rhode Island soils that, while certain functions of potassium in plants may be performed by sodium, potassium is indispensable for other processes, and without sufficient potassium for these requirements, maximum growth cannot be obtained. Krüger (21) in pot experiments with beets in European soils found that, while sodium cannot physiologically replace potassium, its presence permitted plants to use increased quantities of potassium more readily—a very significant point when considered in the light of Hawaiian saline irrigation.

Significant Developments Leading to the Decision to Make the Present Study:

We have stressed the fact that waters from Hawaiian artesian basins contain significant amounts of potash salts. In 1923, Ewa Plantation Company took cognizance of the finding of W. P. Alexander that certain waters from Oahu artesian basins carried sufficient potash, at least theoretically, to supply a major part of the potash requirement of the crop. Utilization of this nutrient from such a source had received little attention up to that time. Noting the fact that cane lands on Maui, cropped for many years, showed no response to potash fertilization, and learning of Mr. Alexander's findings, Dr. A. L. Dean in 1931 proposed that a survey be made of the potash concentration in waters of Alexander & Baldwin, Ltd., plantations. Concurrently W. W. G. Moir, agricultural technologist, American Factors, Ltd., became interested in the subject and made recommendations for research along lines similar to those proposed by Dr. Dean. Accordingly a general potash survey of irrigation waters was made by the Chemistry Department in cooperation with several plantations. These studies seemed to warrant an organized research upon the effect of potash-bearing irrigation waters on soil fertility.

Purpose of the Present Study:

It has been the purpose of the present study: (1) to evaluate the role of potash in irrigation water as it may or may not function in supplying cane requirements in lieu of, or supplementary to, potash fertilization; (2) to determine whether an accumulation of potash may occur in the soil as a result of a great number of successive irrigations with potash-bearing waters; (3) to make a critical comparison of data obtained by determinations of (a) total potash, (b) replaceable potash by neutral normal acetate extraction, (c) one per cent citric acid soluble potash, and (d) potash by rapid field-chemical test.

A logical move, we believed, in such a study was to strike a potash balance for soil, crop, fertilization and irrigation. Such an accounting, if obtainable, may be based upon the potash found in the soil at the moment and that originally existing in the field as shown by analyses of adjacent virgin areas. These figures supplemented by data relative to fertilization and the amounts of the nutrient estimated

to have been removed by successive cropping may be studied in the light of the quantities of potash which may have been added (or removed from) the soil by irrigation waters. Thus a conclusion could be reached, by inference or by calculation, or by both, as to whether the potash carried in irrigation water had or had not functioned as a plant nutrient and, further, whether the potash reserve had been increased or decreased as a result of successive irrigations and croppings.

Plan of the Investigation:

The plan followed in making the study was substantially equivalent to the one just outlined. Soils were selected from a district where crop and fertilization data have been recorded for many years. Determinations of potash were made both in cropped and corresponding virgin areas of the same field. The plan was to learn of any marked deviation in potash concentration of the original soil from that of the cropped area, assuming the corresponding virgin area to approximate the same chemical composition as the field before cultivation.

Field History of Areas Under Consideration:

Through the courtesy of Hawaiian Commercial & Sugar Co., Ltd., and Maui Agricultural Co., Ltd., a total of 100 soil samples from two noncontiguous fields in Central Maui were obtained for us by F. W. Broadbent and O. H. Lyman. Fifty soil samples, representing borings from the surface foot, were collected from each field, twenty-five specimens originating in the cropped area and an equal number in corresponding virgin borders.

Descriptions and records of production and fertilization of these fields are given in Tables I and II.

TABLE I

Crop Production and Potash Fertilization Record.
Hawaiian Commercial & Sugar Co., Ltd.
Field 19B

Crop Year	Variety	Tons Cane Per Acre	Pounds Potash Per Acre Applied as Fertilizer
1911	Lahaina	49.22	73
1912	Lahaina	60.27	88
1913	Lahaina	41.00	70
1914	Lahaina	47.59	66
1915	Lahaina	52.73	24
1916	Lahaina	45.27	28
1917	Lahaina	33.42	0
The field was divided into two parts during the above period, hence a crop is reported for each year. It was fallowed from 1917 to 1923, at which time it was planted.			
1925	H 109	80.27	0
1927	H 109	52.02	0
Again fallowed for two years.			
1931	H 109	61.76	100
1933	H 109	74.99	195
1935	H 109	....	101

TABLE II

Crop Production and Potash Fertilization Record.
Maui Agricultural Co., Ltd.
Field 77

Crop Year	Tons Cane Per Acre	Pounds Potash Per Acre Applied as Fertilizer
1903—(Virgin land)	75	99
1905—First Ratoons	63	99
1907—Second Ratoons	44	99
1910—Plant	64	113
1912—First Ratoons	63	77.5
1914—Second Ratoons	64	87.9
1916—Plant	69	63.6
1918—First Ratoons	43	37.4
1920—Second Ratoons	32	15.8
1922—Plant	50	None
1924—First Ratoons	60	None
1926—Second Ratoons	59	None
1928—Plant	65	None
1930—First Ratoons	87	None
1932—Second Ratoons	78	None
1934—Third Ratoons—uncut	..	..

This field received no pump water prior to 1922. Since that time a large proportion of the water applied during the summer months was supplied by the high-lift pump.

Analytical Procedures:

The air-dried samples were analyzed for total, replaceable and one per cent citric acid soluble potash. This nutrient was also determined by a rapid field-chemical method. Results obtained by the latter test are reported on the basis of air-dried soil. The total replaceable and one per cent citric acid soluble data have been calculated to the moisture-free basis and are so reported. The analytical data are presented in Tables III and IV. The results are tabulated as to cropped areas and corresponding virgin borders. Potash concentrations are expressed as per cent K_2O and as pounds K_2O per acre-foot (pounds/acre-foot) of 2.4 million pounds of soil. Arithmetical averages are presented at the bottom of each column.

Total potash was determined by decomposing the soil with hydrofluoric and sulfuric acids, removing interfering cations and precipitating the potassium as the chloroplatinate.

These figures, of course, include potash in the soluble (available) and insoluble (slowly available) forms, the latter being considered as the nutrient reserve. Proper accounting of the nutrient must take into consideration this total amount, for the net change in concentration of potash in the soil as brought about by fertilization, crop removal, and chemical equilibria changes resulting therefrom, must be reflected in the results obtained by this determination.

Replaceable potash data represent quantities of the nutrient which have been extracted by neutral normal ammonium acetate. These data are given as per cent K_2O in the moisture-free soil rather than as milliequivalents of base per 100 grams of soil.

ried Soil

ıemical Test K_2O Per Cent	Lbs. Per Acre-Ft.
0.046	1,104
0.037	888
0.037	888
0.033	792
0.037	888
0.063	1,512
0.050	1,200
0.044	1,056
0.037	888
0.050	1,200
0.035	840
0.048	1,152
0.063	1,512
0.048	1,152
0.075	1,800
0.063	1,512
0.065	1,560
0 065	1,560
0.040	960
0.070	1,680
0.048	1,152
0.040	960
0.050	1,200
0.046	1,104
0.035	840
0.049	1,176

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1916—Plant	69	63.6
1918—First Ratoons	43	37.4
1920—Second Ratoons	32	15.8
1922—Plant	50	None
1924—First Ratoons	60	None
1926—Second Ratoons	59	None
1928—Plant	65	None
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Replaceable potash data represent quantities of the nutrient which have been extracted by neutral normal ammonium acetate. These data are given as per cent K_2O in the moisture-free soil rather than as milliequivalents of base per 100 grams of soil.

One means of estimating potash in its relation to soil fertility is to determine the amount extracted by a one per cent solution of citric acid. This method has been used extensively at the Experiment Station for many years. Specimens of the soils under investigation had previously and frequently been analyzed by this method; hence the decision was reached to include this type of analysis in the present undertaking.

One of several assemblies the Chemistry Department has recommended to plantations for rapid estimation of soil fertility is a commercially produced ensemble, the operation of which consists in the extraction of the soil with sodium acetate in dilute acid solution and the later formation of turbidity by a precipitation of potassium-sodium-cobaltinitrite in an alcoholic medium. The degree of turbidity indicates the quantity of potash extracted from the soil and hence may be used as a measure of so-called "availability."

Potash in Soil Solution in Relation to Exchangeable Potash:

It is generally considered that plants obtain their nutrient supply only from constituents which are present in the soil in the dissolved state. It does not necessarily follow, however, that nutrients must be applied to the soil in soluble forms in order to be utilized by the crop. Recent experiments conducted by the Chemistry Department as reported by one of us (13) have shown that the cane plant can feed upon phosphates applied in water-insoluble forms.

The amount of potash in the soil solution may be said to bear a relation to that present in the replaceable soil complex. Some of the soluble potash applied as fertilizer may be "fixed" to a greater or less extent. The greater portion of the fixed potash may be found associated with the replaceable complex, the rate and extent of fixation depending upon the concentration of potash in the added solution, the exchange capacity of the soil and the relative amounts of other bases, including hydrogen present in the water.

Discussion of Data—Statistical Analyses:

The replaceable potash content of H. C. & S. Co. Field 19B soils was found to be nearly two and one-half times that found in M. A. Co. Field 77. This applies to both cropped and virgin areas.

Soils of H. C. & S. Co. Field 19B contain a higher percentage of citric soluble potash than M. A. Co. Field 77 soils. A comparison of data obtained from the cropped and virgin areas of both fields shows evidences of a falling off in citric acid soluble potash as a result, apparently, of crop removal.

H. C. & S. Co. Field 19B soils were shown by the above test to possess about three and one-fourth times as much "available" potash as the M. A. Co. Field 77 soils. The comparison between cropped and virgin areas of both fields gives slight indication of removal of this form of the nutrient as a result of cropping.

An examination of the data by one of us shows the virgin soils to be more variable in potash concentration than the corresponding cropped area. A summary of the results obtained by a study of these variations, expressed in terms of the probable error of single determinations (PEs), is presented below. For purposes of comparison the absolute variation has been reduced to per cent variation of the mean (PEs %), or the coefficient of variation:

TABLE V

A Summary Showing the Average Potash Concentrations, Probable Errors of Single Determinations and Coefficients of Variation in Soils of H. C. & S. Co., Field 19B, and M. A. Co. Field 77.

Hawaiian Commercial & Sugar Co. Field 19B

Field	Per Cent K_2O Average	PEs	PEs %	PEs % Virgin Area / PEs % Cropped Area
Total Potash:				
Virgin area	0.909	0.139	15.3	
Cropped area	0.896	0.122	13.6	
Relative variation ...				1.12
Replaceable Potash:				
Virgin area	0.1268	0.0161	12.6	
Cropped area	0.1293	0.0135	10.4	
Relative variation ...				1.21
1 Per Cent Citric Acid Soluble Potash:				
Virgin area	0.1198	0.0260	21.7	
Cropped area	0.0977	0.0150	15.3	
Relative variation ...				1.42
Rapid Field-Chemical Test Potash:				
Virgin area	0.049	0.0083	17.0	
Cropped area	0.042	0.0046	11.0	
Relative variation ...				1.55

Maui Agricultural Co. Field 77

Field	Per Cent K_2O Average	PEs	PEs %	PEs % Virgin Area / PEs % Cropped Area
Total Potash:				
Virgin area	0.926	0.0825	8.9	
Cropped area	0.890	0.0760	8.6	
Relative variation ...				1.04
Replaceable Potash:				
Virgin area	0.525	0.0103	19.8	
Cropped area	0.528	0.0070	13.2	
Relative variation ...				1.50
1 Per Cent Citric Acid Soluble Potash:				
Virgin area	0.0432	0.0104	24.0	
Cropped area	0.0304	0.0040	13.1	
Relative variation ...				1.84
Rapid Field-Chemical Test Potash:				
Virgin area	0.015	0.0036	23.9	
Cropped area	0.011	0.0019	17.2	
Relative variation ...				1.39

The statistical study of the data reveals wide differences between the average values and those of single determinations, thus indicating high soil variation. The coefficients of variation range from 8.6 to 24.0 per cent. Reference to columns 3 and 4 above will show that although such fluctuations exist, differences between virgin and cropped areas are small in most cases. However, a consistently higher variation exists in the virgin soils.

Interpretation of Data Relevant to Fertility. "The Net Normal Potash Requirement":

The scope of the following discussion will be confined to the interpretation of the results relevant to fertility as influenced by the potash occurring in irrigation water. The term "fertility" refers to the capacity of the soil to furnish nutrients.

Using data already presented we look into the matter of crop removal and fertilization in an effort to gain some knowledge reflecting upon any net change in the total potash content of the soils under study. While the minimum quantity of potash required to produce a normal crop of cane has not been accurately determined, the average amount removed has been estimated from researches of Stewart (30), Stewart and Verret (31) and Ayres (1) as approximating 200 pounds of K_2O per 100 tons of millable cane. Calculating on this basis and summarizing Tables I and II, the net amounts of potash used for crop production in excess of that supplied by fertilizers on the Maui areas are as follows:

	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Crops harvested (long crops of 2 years each)	8	16
Crops standing in field at time of soil sampling	1	1
Tons cane per acre harvested	434	916
Pounds K_2O removed by crop as calculated on basis of 200 pounds per 100 tons of millable cane	868	1832
Amount K_2O estimated in standing crop	100	100
Total K_2O removed by crops	968	1932
K_2O added in fertilizers	470	692
Net amount of K_2O in pounds removed by crops above that supplied in fertilizers*	498	1240

* This item will be referred to in the discussion as the "net normal potash requirement of the crop."

Thus it appears that 498 pounds K_2O for H. C. & S. Co. Field 19B and 1240 pounds for M. A. Co. Field 77 represent the net amounts which must have been supplied either by the soil or the irrigation water to meet the requirements of the crops produced.

A statistical examination of the data relating to total potash in the two fields shows no significant differences between the cropped and virgin areas.

STATISTICAL ANALYSIS OF TOTAL POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average for virgin area	0.909 ± 0.0277	0.926 ± 0.0165
Average for cropped area	0.896 ± 0.0244	0.890 ± 0.0153
Difference, virgin minus cropped area	0.013 ± 0.037	0.036 ± 0.022
Difference, in pounds K_2O/acre-foot	312	864
Difference ÷ probable error of difference	.35 P. E.	1.64 P. E.
Reliability of difference	Not significant	Not significant

Generalizations Based Upon Data and Field History:

From a consideration of the above data one may conclude that since the total potash content of the soils has not materially changed, the successive irrigations have produced no residual effect. If this be true then we have indications supporting the hypothesis that the net normal potash requirement must have been furnished by the irrigation water applied to the fields.

The potash concentration of the artesian water supplied H. C. & S. Co. Field 19B varied from 26 to 60 parts per million K_2O, and that furnished M. A. Co. Field 77 varied between 32 and 42 parts per million K_2O. From records at hand we believe it reasonable to assume that the potash content of pump water applied to both fields averaged not less than 25 parts per million or 208 pounds K_2O per million gallons of water.

Generalizing further and using as a basis of calculation a value of 3 million gallons of water per long crop, for the eight crops under consideration, we find that approximately 5000 pounds K_2O have been carried to H. C. & S. Co. Field 19B. It is not improbable that the crops obtained the 498 pounds net normal requirement of potash from the total of 5000 pounds supplied in irrigation. Furthermore, since there has apparently been no building up of potash in the soil, then of the remaining 4502 pounds the amount in excess of that lost by leaching must have been used by the plants in luxury consumption.

A study of the field history of M. A. Co. Field 77 reveals the fact that no pump water had been applied previous to 1922 and that, during subsequent years, artesian water has been used, with rare exceptions, only during the summer months. A slight decrease was found in total potash in the cropped soil as compared with the virgin area. This difference of 0.36 per cent K_2O, representing 1.6 times the probable error, although not absolutely significant mathematically, is, we believe, an indication that incipient depletion may be taking place. Mountain water, which supplies the major portion of the irrigation requirement for this field, contains an average of only 2 parts per million potash, an amount equivalent to 16 pounds K_2O per million gallons. The data reviewed thus far, and those which are to follow, seem to indicate that potash in irrigation water, in order to merit consideration in the fertilizer schedule, must be present in excess of a certain minimum concentration.

Replaceable Potash in the Soil With Respect to the Net Normal Potash Requirement:

Many investigators have found that as a result of the practice of continued cultivation without supplying potash in excess of that removed by crops, the replaceable potash content of the soil will be lowered. Citations to researches on this topic have been presented previously in this paper. In view of the many years of cropping undergone by the Maui fields, and considering again the resulting net normal potash requirement of these soils, it is reasonable to expect that the exchangeable potash in the cropped area will be found to be lower in amount than in the virgin area, providing the nutrient has not been introduced from some other source.

A statistical analysis of the data previously presented shows that the concentrations of potash in the cropped areas have undergone no significant changes as compared with those of the virgin localities. Hence, we find support for the presumption that the potash carried to the soil by the irrigation water may account for this finding. The following summary is self-explanatory:

STATISTICAL ANALYSIS OF REPLACEABLE POTASH DATA

	Per Cent Potash (K_2O) H. C. & S. Co. Field 19B	Per Cent Potash (K_2O) M. A. Co. Field 77
Average of cropped area	0.1293 ± 0.0027	0.0528 ± 0.0014
Average of virgin area	0.1268 ± 0.0032	0.0525 ± 0.0021
Difference, virgin minus cropped area	0.0025 ± 0.0042	0.0003 ± 0.0025
Difference, in pounds K_2O/acre-foot	60	72
Difference ÷ probable error of difference	0.59 P. E.	0.12 P. E.
Reliability of difference	Not significant	Not significant

Statistical figures appear to offer corroboration of the presumption that the irrigation water may have supplied the net normal requirement for crop production. Fraps (8) in his researches found that the total amount of potash removed by a crop from the soil averaged about 3 to 16 times the water soluble potash lost by the soil as a result of crop removal, and about twice the replaceable potash lost in this way. It is of interest to note that in the present study while the difference in quantity of replaceable potash in cropped over virgin area is of no absolute statistical significance, the averages indicate a trend towards a gain rather than a loss. On the other hand, a study of the data relevant to citric soluble analyses shows large decreases in the cropped areas in potash soluble in this medium. Statistical examination of these figures appears below:

STATISTICAL ANALYSIS OF ONE PER CENT CITRIC ACID SOLUBLE POTASH DATA

	Per Cent Potash (K_2O) H. C. & S. Co. Field 19B	Per Cent Potash (K_2O) M. A. Co. Field 77
Average of virgin area	0.1198 ± 0.00520	0.0432 ± 0.00211
Average of cropped area	0.0977 ± 0.00301	0.0304 ± 0.00080
Difference, virgin minus cropped area	0.0221 ± 0.00600	0.0128 ± 0.00225
Difference, in pounds K_2O/acre-foot	530	308
Difference ÷ probable error of difference	3.68 P. E.	5.70 P. E.
Reliability of difference	Practically significant	Absolutely significant

One Per Cent Citric Soluble Potash and Its Relation to the Net Normal Potash Requirement:

While a difference of four times the probable error is considered significant, 3.68 times the probable error may, for practical purposes, be placed in the same category. The statistical results point to an absorption of potash soluble in one per cent citric acid by the plants in both fields. If the net normal potash requirement of the crop came wholly from potash extractable by one per cent citric acid, then the amount shown to be needed by the H. C. & S. Co. Field 19B may be con-

sidered as having been supplied by the soil. However, this consideration does not hold true in the case of M. A. Co. Field 77. The net normal requirement for this field was calculated as 1240 pounds of K_2O and that represented by the citric acid soluble portion was only 308 pounds. Obviously then, 1240 minus 308, or 932 pounds, must have come from another source. Since there has been no change in the concentration of replaceable potash in cropped and virgin areas, the 904 pounds of K_2O must have been furnished directly by the water. Plants are known to absorb the most easily soluble forms of potash; it is conceded, we think, that potash in irrigation water is unquestionably in solution. Hence, uptake directly by the plant from this source is reasonably possible, and the evidence just cited points to such an absorption.

Potash Determined by the Rapid Field-Chemical Test and Its Relation to Cropping:

A mathematical examination of the results obtained by the rapid field-chemical test shows significant differences to exist in the cropped and virgin areas in both cases. The results are summarized in the following schedule:

STATISTICAL ANALYSIS OF RAPID FIELD-CHEMICAL TEST POTASH DATA

	Per Cent Potash (K_2O)	
	H. C. & S. Co. Field 19B	M. A. Co. Field 77
Average of virgin area	0.049 ± 0.00167	0.015 ± 0.00072
Average of cropped area	0.042 ± 0.00092	0.011 ± 0.00038
Difference, virgin minus cropped area	0.007 ± 0.0019	0.004 ± 0.0008
Difference, in pounds K_2O/acre-foot	168	96
Difference ÷ probable error of difference	3.7 P. E.	5.0 P. E.
Reliability of difference	Practically significant	Absolutely significant

The deficiency in balance of 168 and 96 pounds of potash in the soils as revealed by the rapid field-chemical analyses is insufficient to account for the net normal requirements of 498 and 1240 pounds of K_2O of the respective fields (H. C. & S. Co. Field 19B and M. A. Co. Field 77). It is evident that uptake of potash from a supply in the soil or from added fertilizer must have occurred. Hence, from full consideration of the treatment the fields received and from the data, indications again point to an absorption of potash from irrigation water.

While the percentages of K_2O obtained by the rapid field-chemical method are considerably lower, in general, than those obtained by the one per cent citric acid method, the data derived by both methods are comparable and appear related. Both methods involve acid extraction. In the present study citric acid soluble results bear an average value of 2.6 times that obtained by the rapid field-chemical test. Using this factor, and recalculating the rapid field-chemical test data comparable with the citric acid results, we find that the deficiency in balances of potash in the soils becomes 437 and 250 pounds of potash respectively instead of 168 and 96 pounds. Once more we learn that while in the case of H. C. & S. Co. Field 19B ample potash may have been removed from the soil to make up the net normal requirement, data of M. A. Co. Field 77 reveal a discrepancy of 1240 minus 250 or 990 pounds of potash which, in this case, must have been furnished by the

irrigation water. This finding is therefore in support of the conclusion that potash in irrigation water can and will contribute to plant fertilization.

Fixation in Soils by Potash Contained in Irrigation Water:

Some of our conclusions based upon the data pertaining to replaceable and citric acid soluble potash obtained in the study of the Maui soils are in accordance with observations of McGeorge (26). In his study of the availability of potash in Hawaiian soils, McGeorge found that, for some soils, the addition of potash fertilizers increased the replaceable potash but not the potash extractable by one per cent citric acid. He concluded from his study that in the case of some soils the potash is fixed in a form insoluble in one per cent citric acid.

It is conceivable that plants, when in need of a relatively large supply of potash, may draw upon easily obtainable reserves in the soil. Potash thus removed from the soil may later be replaced by potash contained in the irrigation water. If this be true, then there is reason to believe that the potash thus replaced is more firmly fixed than that originally removed in cropping, for, as successive extractions by the plant take place, we find the concentration of citric acid soluble potash diminishing. The fixation of potash in the soils studied appears to be associated with the replaceable complex. Considering the large amount of potash carried to these fields by the irrigation water, the lack of an increase in the total supply in the soil gives indication that very little is fixed in the non-replaceable or difficultly available state. Volk (33) found that alternate wetting and drying of a soil contributed to the fixation of potash in the non-replaceable fraction, the extent of fixation depending upon the nature and quantity of the soil colloids. However, in his examination of three specimens of Hawaiian soils he found no fixation in two and only to a slight degree in the third.

The fixation of potash in the replaceable complex in the Maui soils, only to the extent of the maintenance of the original level, may be accounted for by the reduction of the base-exchange capacity resulting from the diminution of organic matter in the soil through continuous cultivation. A comparison of the analytical results obtained from the 100 samples shows replaceable potash to be present in amounts about 3.5 times greater than those determined by the rapid field-chemical method.

Availability of Soil Potash as Affected by Cropping and Addition of Potash by Irrigation Water:

The question of availability of the potash determined by various methods, while not directly involved in the present investigation, does, however, warrant some attention. A discussion of the topic as affecting the M. A. Co. Field 77 will illustrate the point. Potash fertilization was discontinued from 1922 until quite recently, an interval of approximately 12 years. The major portion of the irrigation water supplied originated in mountain sources and contained a very low concentration of potash. The analytical results obtained in the present soils study show potash to be present to the extent of:

	Per Cent Potash (K_2O) Cropped	Virgin
Total (K_2O) (1933)	0.0890	0.0926
Replaceable K_2O (1933)	0.0528	0.0525
One per cent citric soluble K_2O (1933)	0.0304	0.0432
One per cent citric soluble K_2O (1927)	0.0550	.....

The figures in the summary show no significant change for total potash, although a trend towards a decrease is in evidence. There is likewise no reduction of replaceable potash, but a measurable loss of citric soluble potash was found in the cropped areas as compared with the virgin soils.

Between the years 1928 and 1933 two field tests in potash fertilization were conducted upon cane areas in the same locality. At the beginning and at the conclusion of these tests, soil analyses were made using the one per cent citric acid extraction method. Potash found in the 1927 citric soluble analysis (7) averaged 0.055 per cent K_2O, whereas the 1933 figure showed a concentration of .03 per cent, a reduction of almost 50 per cent in the 6-year period. The 1930 harvesting results showed no response to applications up to 300 pounds K_2O per acre. The 1932 results indicated no significant gains, but a tendency to respond was reported with an application of 120 pounds.

With respect to H. C. & S. Co. Field 19B, a drain corresponding to that found in M. A. Co. Field 77 is not evident. The following ratios are presented:

SUMMARY OF RATIOS OBTAINED BY CALCULATING FROM THE POTASH AVERAGES OF THE AREAS

	Citric Acid Soluble / Replaceable	Rapid Fld.-Chem. Test / Citric Acid Soluble	Replaceable / Total
H. C. & S. Co. Field 19B:			
Cropped area	.76	.43	.14
Virgin area	.95	.40	.14
M. A. Co. Field 77:			
Cropped area	.575	.362	.059
Virgin area	.825	.346	.057

It will be seen that while the citric acid soluble potash in H. C. & S. Co. Field 19B cropped soil is lowered in concentration, it is still 76 per cent of the replaceable potash, whereas in the cropped soil of M. A. Co. Field 77 the concentration has been reduced to 57.5 per cent of the replaceable potash of that area.

Investigators have shown that plants will absorb potash in large quantities up to a maximum regardless of the needs of the plant for this nutrient. The results obtained by Bartholomew and Janssen (2, 3) indicate that plants have a large capacity for absorption of potassium and that the absorption will be maintained throughout the life of the plants if sufficient available potassium is present in the feeding area of the roots. The uptake of potash by plants is influenced not only by the amount available, but by the presence of other nutrients. Phosphate has been found to influence the uptake of potassium. Sodium has been reported as exercising a similar effect, as noted previously. H. C. & S. Co. Field 19B soils contain a high concentration of readily soluble potash and with the use of irriga-

tion water carrying a high salt (sodium chloride) content, a condition may be suggested as existing in the field which makes for maximum uptake of potash by the cane. The data at hand appear to indicate that additional applications of potash as fertilizer to this field are not necessary. Such additions in the past appear to have resulted in little residual building up in the soil. On the contrary, any application in excess of the minimum requirement of the crop may contribute to luxury consumption.

Factors Influencing the Use of Irrigation Water as a Source of Potash:

If the employment of pump irrigation water is to merit a place in the fertilizer schedule, the following factors, we believe, will have to be considered:

1. Potash concentration of water and total volume used.
2. The concentration of readily soluble potash in the soil as determined by neutral normal ammonium acetate extractions or by the one per cent citric acid method.

From studies so far conducted it is problematical whether mountain water low in potash has any fertilizer value. To decide this issue, a research patterned along lines of the one now concluded might be made to advantage on the fields using mountain water irrigation exclusively.

The artesian water studied in this investigation carried comparatively high concentrations of potash. One of the Maui fields received only a fraction of its water from artesian sources. Since this field gave indications corresponding to those obtained from the area receiving pump water entirely it is safe to assume, we believe, that 10 parts per million, or 80 pounds K_2O per million gallons, is a low limit of concentration below which irrigation water may not merit consideration as a source of potash. However, a modification of this minimum will be permissible if the amount of available potash present in the soil is given consideration.

A marked relationship is noted by some investigators between the amount of replaceable potash in the soil and response by plants to potash fertilization. Magistad (23) found no response to potash added to pineapples grown in field experiments on Hawaiian soils when the quantity of replaceable potash present in the soil exceeds 0.4 to 0.5 milliequivalent per 100 grams of dry soil, or approximately 500 pounds K_2O per acre-foot. Similar correlation for sugar cane grown in Hawaiian soils has as yet not been determined.

Where the supply of available potash existing in the soil is sufficiently high to meet contingencies of increased plant demand, then potash present in the irrigation water, though of a lower concentration than the suggested minimum of 10 parts per million, can still be considered as an available source of this nutrient. Utilization of potash contained in irrigation water may be likened to split applications of fertilizers. According to reports of previous workers a large demand is made upon the soil potash during the boom stage of growth of the cane plant. Sufficient available potash should then be present in the soil to compensate for the smaller applications from water of low potash concentration. For areas receiving water of high potash concentration, say in the neighborhood of 20 parts per million (equal to 160 pounds of K_2O per million gallons), it appears that reserves of im-

mediately available potash in the soil may not be needed. In either case, however, sufficient volume of water should be employed to insure the application of ample amounts of the nutrient.

Conclusions

Successive applications of irrigation water high in potash have apparently created no significant residual effect with respect to this nutrient in the soils studied.

The crops harvested removed more potash than was supplied through artificial fertilization.

The quantity of potash removed by the crops in excess of that supplied by the soil and artificial fertilization is believed to have been furnished by the pump irrigation water used.

Large amounts of naturally occurring potash applied in the irrigation water to soils already rich in the nutrient appear to contribute to luxury consumption.

Potash in irrigation water merits consideration in the fertilizer schedule provided the concentration exceeds 80 pounds per million gallons and the quantity of water used insures a total application sufficient or perhaps somewhat in excess of the requirement of the crop. For soils of low available potash concentration a total application per crop of about 250 pounds of potash from irrigation water apparently may insure soil fertility with respect to this nutrient.

Hawaiian artesian waters contain potash sufficient to meet the normal requirements of a culture solution regarding this nutrient.

Virgin cane areas appear to be more variable in potash composition than soils in cropped fields.

The rapid field-chemical tests for soil potash yields results which are comparable with those obtained by the one per cent citric acid soluble method.

Data from the two fields studied show that replaceable potash determinations bear an average relationship of 1.3 times the one per cent citric acid soluble results and 3.5 times the rapid field-chemical test results.

Summary

Water used for irrigation on Hawaiian cane lands contains potash in variable amounts, the concentration depending upon the source of the water. A study to determine whether such naturally occurring potash contributes to sugar cane fertilization has been completed upon soils from two districts.

The solution of the problem was attempted by striking a balance between the quantity of potash existing in the soil before and after cropping, the amount added as fertilizer and the total removed by a number of crops. A discrepancy in potash balance, if found, might then be shown to have been made up by the irrigation water.

Two fields in central Maui were selected for the study. These fields have received applications of artesian water for a number of years. Crop and fertilization records were supplied through the courtesy of the plantations.

A total of 100 soil samples were analyzed for potash by the replaceable, one per cent citric acid, rapid field-chemical, and total potash methods. In addition to evaluating the data in the light of the problem, a comparative study was made

of the analytical results obtained by the various methods employed.

Potash removed by the crops of both fields was in excess of that supplied by fertilizers and that lost by the soil. As a result of the study, indications are found which support the premise that the potash occurring in irrigation water functions in plant nutrition.

Acknowledgment

The authors express their thankful appreciation to Dr. A. L. Dean of Alexander & Baldwin, Ltd., and Mr. W. W. G. Moir of American Factors, Ltd., for the encouragement and interest shown during the progress of these studies. We are indebted to Dr. O. C. Magistad, chemist, Experiment Station of the Pineapple Producers' Cooperative Association, Ltd., for advice and assistance rendered us and for the interest shown in furthering this research. We are likewise grateful to Mr. Ward D. Walker, Assistant Manager, and Mr. Frank Broadbent, Agriculturist, Hawaiian Commercial & Sugar Co., Ltd., to Mr. H. A. Baldwin, Manager, Maui Agricultural Co., Ltd., and to Mr. O. H. Lyman, Maui Representative of the Experiment Station, for the courtesy shown us in supplying field data and for their assistance or direction in obtaining the soil samples used in these studies. We acknowledge also the cooperation extended us during the progress of the work by Messrs. R. Borden and Arthur Ayres of the Experiment Station Staff.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
MARCH 16, 1934, TO JUNE 15, 1934.

Date	Per Pound	Per Ton	Remarks
March 16, 1934..........	3.09¢	$61.80	Puerto Ricos, 3.08, 3.10; Philippines, 3.10.
" 17...............	3.06	61.20	Philippines.
" 19...............	3.06	61.20	Puerto Ricos, 3.05; Philippines, 3.07.
" 20...............	3.02	60.40	St. Croix.
" 21...............	2.9733	59.47	Philippines, 2.95, 2.97, 3.00.
" 22...............	2.95	59.00	Philippines.
" 23...............	2.97	59.40	Philippines.
" 24...............	2.95	59.00	Puerto Ricos.
April 5...............	2.90	58.00	Philippines.
" 6...............	2.8625	57.25	Puerto Ricos, 2.83, 2.85, 2.90; Philippines, 2.85, 2.87, 2.90.
" 7...............	2.83	56.60	Philippines.
" 9...............	2.79	55.80	Philippines, 2.78, 2.80.
" 10...............	2.72	54.40	Philippines.
" 13...............	2.725	54.50	Philippines, 2.70, 2.75.
" 16...............	2.70	54.00	Philippines.
" 17...............	2.725	54.50	Puerto Ricos, 2.72, 2.73.
" 19...............	2.71	54.20	Philippines, 2.70; Puerto Ricos, 2.72.
" 20...............	2.70	54.00	Philippines.
" 21...............	2.735	54.70	Puerto Ricos, 2.72; Philippines, 2.75.
" 24...............	2.74	54.80	Philippines, 2.73, 2.75.
" 26...............	2.80	56.00	Puerto Ricos.
May 1...............	2.75	55.00	Philippines.
" 4...............	2.78	55.60	Philippines.
" 5...............	2.80	56.00	Philippines.
" 8...............	2.82	56.40	Philippines.
" 9...............	2.85	57.00	Puerto Ricos.
" 11...............	2.83	56.60	Philippines.
" 15...............	2.80	56.00	Philippines, St. Croix.
" 18...............	2.775	55.50	Philippines, 2.75; Puerto Ricos, 2.80.
" 19...............	2.75	55.00	Philippines.
June 1...............	2.74	54.80	Philippines, 2.73; Puerto Ricos, 2.75.
" 2...............	2.73	54.60	Philippines.
" 4...............	2.74	54.80	Puerto Ricos, 2.73, 2.75.
" 5...............	2.755	55.10	Philippines, 2.73; Puerto Ricos, 2.78.
" 6...............	2.78	55.60	Puerto Ricos, Philippines.
" 7...............	2.765	55.30	Philippines, 2.73; Puerto Ricos, 2.80.
" 8...............	2.80	56.00	Puerto Ricos.
" 14...............	2.91	58.20	Philippines, 2.80; Puerto Ricos, 2.90; 3.03.
" 15...............	3.05	61.00	Puerto Ricos.

THE HAWAIIAN PLANTERS' RECORD

Vol. XXXVIII FOURTH QUARTER, 1934 No. 4

A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the plantations of the Hawaiian Sugar Planters' Association.

In this Issue:

Light Showers and Dew as a Source of Moisture for the Cane Plant:

Recent irrigation studies at Waialua Agricultural Company, under the authority of a cooperative project between that plantation and the Experiment Station, H.S.P.A., give additional evidence that light showers and dew falls may be of decided significance in the water economy of the cane plant.

Previous work with the same cane variety in tanks at Waipio gave similar results. This short paper summarizes these observations on the water-absorbing characteristics of the aerial parts of the cane plant and suggests additional work on this subject. A clear understanding of this important physiological characteristic is of great commercial as well as scientific interest.

Measures for the Control of Anomala Orientalis at the Oahu Sugar Company:

Extensive studies of *Anomala orientalis* populations at Oahu Sugar Company, Ltd., have been made by the plantation. Large-scale efforts in the artificial control of this insect, by many methods, have also been completed, some of which proved to be effective. Detailed data covering this work are given, which include procedures, materials and results.

Predisposing Factors in Pythium Root Rot:

No disease of sugar cane has been more obdurate than root rot. It has occurred in various parts of the world to bring about the decline of the cane variety known elsewhere as Bourbon, locally as Lahaina. Failures of this cane in some regions were reported as early as 1846; here the Lahaina variety began to fail before 1900 and by 1920 was being rapidly replaced by H 109.

Suspicious cases of failure of H 109 caused renewed interest in root rot studies, but such failures were found in general to be related to other causes.

High nitrogen fertilization was found to be a predisposing cause of severe root rot attack in susceptible varieties, and of slight attack in resistant canes.

Recently, canes ordinarily resistant have been found to suffer pronounced root injury from *Pythium,* in certain areas, in the absence of heavy phosphate fertilization. There are indications that there is sufficient available phosphate for growth, could the plants be kept free of *Pythium,* but not enough to throw the balance in favor of the cane when it is present.

This type of growth failure is discussed as another example of the destructive action of *Pythium* when the cane roots are preconditioned by sub-normal nutrition. The situation is further complicated by the occurrence of aluminum salts in high concentration in these soils, and no doubt aggravated by low temperatures and poor conditions of soil moisture.

The paper deals largely in a review of work elsewhere on *Pythium* fungi in relation to other crops and a comparative study is made between the findings of local workers and those of other investigators.

Light Showers and Dew as a Source of Moisture for the Cane Plant

By H. A. Wadsworth

It has long been recognized that a statement of the annual precipitation in an agricultural region is not a satisfactory basis for judging the local necessity of irrigation. Seasonal distribution is of greatest importance.

For deep-rooted crops the ideal distribution of rainfall has been described as a series of independent rains, each of sufficient duration to wet the soil to the depth of greatest root penetration with no losses by surface run-off. Rains of greater duration than this result in wetting the soil to greater depths than can be reached by the plant roots, while a series of light showers, although they may add up to an appreciable precipitation in a year, contribute little to the well-being of a deep-rooted crop. In some regions it is customary to estimate the effective rainfall by dividing the annual precipitation by two, assuming that half of the annual rainfall is unavailable for plant use because of surface run-off, excessive penetration, or surface evaporation.

Similar arguments have been advanced with respect to the requirements of the sugar cane plant and it has been said that showers of less than half an inch are negligible in the water economy of the plant. Here the assumption is made that the effect of such showers on a young field is minimized by the unavoidable losses through surface evaporation, while such showers on a field of big cane are insufficient to penetrate the trash blanket covering the soil.

The Local Situation

Sound as this argument may appear from acknowledged principles of soil physics and from previous studies with other plants, it does not seem to be in accord with many local observations upon sugar cane. A field on Maui produced a satisfactory yield of both cane and sugar with an irrigation interval, before harvest, of about 300 days. The showers during this period were described as being well distributed but too slight to affect the soil moisture content.

Moreover, field men have often observed the stimulating effects of rains too insufficient in amount to increase the moisture content of the soil upon which the cane was growing. In some cases heavy dew is mentioned as an aid in reviving cane which had shown the first signs of wilt.

More concrete evidence of the significance of light showers on cane growth is provided in the elaborate irrigation studies being conducted at the Waialua Agricultural Company under a cooperative agreement between that plantation and the Experiment Station, H.S.P.A. Swezey (7), representing the Experiment Station in this cooperation, reports as follows:

During the past month the rates of cane growth have followed the conditions of weather (rainfall and dewfall) and soil moisture in the same way as reported two months ago. You will

note that I mention dewfall as a weather condition. It *is*, of course, a phase of daily weather but I wish particularly to refer to dewfalls and light rainfalls as they have been observed during the past month. (By light rainfalls I mean amounts of rain up to 0.20 or 0.30 inch per day.)

We have noted on several occasions that when the soil moisture has been approximately at or slightly below the wilting point there have occurred the heavy dewfalls or light rainfalls mentioned. The rate of growth at those times has not declined as was expected on account of the depleted soil moisture. Coincidental with the dew or light rainfall, we observed no increase in soil moisture.

One would not, I believe, expect a heavy dew to raise the moisture content of the soil. Also, the cane during the past month has closed in well and consequently light showers of rain are caught on the cane leaves and the soil receives no water. (A minimum of from 0.50 to 1.00 inch of rain is the smallest amount capable of penetrating the leaf screen and reaching the ground.)

The evidence seems to indicate that enough water is absorbed by the leaves or the bases of the leaves to keep the plants growing in spite of lack of sufficient moisture in the soil. . . .

Evidence From Other Stations

Although such light rains and dews have never before been considered as important supplements to irrigation, some academic aspects of the aerial absorption of moisture by plants have been reported in the literature.

Maximov (5) reviews the results of early workers in the field under the heading "Absorption of Water by the Aerial Organs of Plants." General as the title is, it is devoted largely to detailed work on the absorptive capacity of leaf tissue. Although some attention is given to epiphytes, no mention is made of the possibility of absorption through the nodal zones in the case of grasses.

In 1930 Hiltner (3) reported the results of a long series of experiments under the title, "Dew and Its Significance in Plant Growth." This author asserts in his summary that dew is an economically important meteorological factor, the influence of which in practical plant growth is unjustly neglected. Another significant statement is that with certain plants the moisture intake of the leaves may be substantial in amount in relation to the total moisture consumption of the plant.

However, Livingston (4) seems to feel that the effect of dew and light rains in the water economy of plants is due to the reduction of losses by transpiration and not to the actual absorption of water in significant amounts through leaf and stem surfaces.

It remained for Breazeale (1) to observe what appears to be an increase of soil moisture around the roots of a plant because of the discharge of water through the roots. Breazeale used corn growing in the experimental fields of the Arizona Station. Long brace roots which had just reached the soil surface but had not yet developed laterals were inserted into small glass jars, which were subsequently filled with dry soil. The opening was then sealed with a warm paraffin-beeswax mixture. An apron of oilcloth was provided as further protection. An increase in moisture content in the soil in the jar was usually noted; in cases where the roots in the jar approached the glass a small zone of moist soil could be detected even before the root appeared in view. Breazeale concludes that the root tip was exuding water which kept a moist zone of soil in front of and in direct contact with the elongating root.

Hendrickson and Veihmeyer (2) fail to substantiate the general application of this principle after a comprehensive series of greenhouse experiments with sunflowers and beans.

It is interesting to note, however, that Breazeale in his publications fails to note the effect of rain upon his small jars of dry soil containing the brace roots from the corn plants. Dr. O. C. Magistad,* who worked in close association with Breazeale, reports that a rain occurring during the time of observation increased the moisture content of the soil in the jar to such an extent that Breazeale suspected the adequacy of his seal. The similarity of this experience with that secured locally with sugar cane is suggestive.

Local Observations

Occasional references (6), (9), (8) in the local reports of studies in the relation of the sugar cane plant to moisture indicate that the sugar cane plant may have characteristics similar to Breazeale's corn. Remarkable gains in soil moisture during showers, either natural or artificial, have been experienced which can be accounted for only by, (1) assuming that the experimental technique was much poorer than it appeared, or (2) endowing the sugar cane plant with the capacity of absorbing large amounts of water in its aerial parts, the conveyance of this water into the root zone and its discharge into the soil mass.

Unwilling as the observers were to admit the first of these alternatives, it appeared necessary in view of the inconclusive nature of the evidence. The temporary curtailment of such studies has made it impossible to continue the work.

However, the field work at Waialua makes it necessary that additional consideration be given to this aspect of the general problem, if a true understanding is desired.

The following summary of the experimental evidence as to the water-absorbing capacity of sugar cane is given to focus attention once more upon an aspect of sugar cane physiology which is not only of great scientific interest but of considerable commercial value as well.

The tank equipment at Waipio has been often described (6). In brief, it consisted of a series of large cylindrical tanks, each holding about a ton of soil and so placed that it might be quickly and rather accurately weighed. Germinated eyes of H 109 cane were planted in each tank on April 5, 1929, and the tanks irrigated to maximum field capacity by the aid of a suspended balance.

When mature cane had formed, wooden covers were framed to fit the area between the rims of the tanks and the opening in the center, which was left for the development of the sticks. This opening was plugged with machinist's waste and this waste coated with paraffin. The spaces between the rims of the tanks and the wooden covers were caulked in the same way. It was assumed that such seals would protect the soil surfaces from evaporation as well as exclude rain, except that which might beat through the seal under a driving wind.

* Chemist, Pineapple Producers Cooperative Association.

The summer of 1929 was remarkably dry. No significant precipitation occurred until August 25, when the plants were about five months old. A shower of 0.58 inch on August 25 resulted in erratic increases in weight in most cases.

The increases in weight for the several tanks under the influence of the August shower are summarized in Table I.

TABLE I.

Increases in gross tank weights due to precipitation of 0.58 inch, August 25, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	11	8	5
2	8	9	3
3	1	10	5
4	6	11	13
5	4	12	8
6	—2	13	—8
7	11	14	4

The irregular gains in weight in most tanks were attributed to faulty seals and to lack of precision in the weighing equipment. It is assumed that the balance was reliable to the nearest five pounds.

A second heavy rain of 3.00 inches on September 24 and 25, 1929, ruled out the possibility of inaccurate weighings and concentrated attention on the nature of the seals. The results of the September rain are given in Table II.

TABLE II.

Increases in gross tank weights due to precipitation of 3.00 inches, September 24 and 25, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	79	8	109
2	75	9	90
3	53	10	107
4	84	11	93
5	86	12	71
6	52	13	50
7	51	14	72

Such tremendous gains were beyond any possible error in the scales and since the main problem demanded precise soil moisture control, every effort was expended to improve the nature of the seal. Oilcloth aprons were fixed to each tank, this material being sealed to the mature sticks with a mixture of petrolatum and paraffin and the junction subsequently painted with shellac.

Gains in weight persisted after these precautions. A shower of 1.79 inches on October 5, 1929, resulted in gains in weight as reported in Table III.

TABLE III.

Increases in gross tank weights due to precipitation of 1.79 inches, October 5, 1929.

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	20	8	45
2	44	9	32
3	5	10	37
4	36	11	18
5	34	12	36
6	31	13	35
7	16	14	40

Still dissatisfied with the nature of the seals, a new procedure was devised which to all appearances would make the passage of water impossible. The new seal involved the use of a high-grade roofing asphalt and powdered resin. The material was melted over an open fire and poured over the wooden covers and waste plugs to a depth of about one and one-half inches. The hot mixture was brushed up onto the mature sticks coming through the seal, and over the edges of the tank.

The period from November 1 to 7, 1929, was particularly wet at Waipio, the tank farm rain gage indicating a total precipitation of 7.11 inches during the period. In spite of the character of the seals most of the tanks gained significantly in weight during this week of heavy precipitation. Gains in weights are shown in Table IV.

TABLE IV.

Increases in gross tank weights due to precipitation of 7.11 inches, November 1 to 7, 1929. (During this period the tanks were equipped with asphalt seals.)

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	47	8	—2
2	45	9	—3
3	23	10	11
4	52	11	99
5	22	12	79
6	32	13	36
7	29	14	20

Additional showers from December 10 to 17, 1929, increased the weight of all tanks except No. 9. The asphalt seals were still in place. Detailed gains are shown in Table V.

TABLE V.

Increases in gross tank weights due to precipitation of 3.29 inches, December 10 to 17, 1929. (Asphalt seals in place.)

Tank Number	Gain in Weight (pounds)	Tank Number	Gain in Weight (pounds)
1	16	8	55
2	30	9	—1
3	15	10	(see below)
4	24	11	37
5	35	12	30
6	9	13	11
7	15	14	17

In addition to these series of observations, in which all tanks were used under natural precipitation, other tests were made on selected tanks subjected to artificial showers.

Tank No. 8 was sealed with asphalt and resin on October 15. A stream of water from a garden hose was run over the seal for an hour after careful note had been made of the gross weight. A second careful weighing at the end of this treatment showed that no increase had occurred. Since the stream from the hose had been applied to the critical points in the seal, it was assumed that the seal was adequate against leak. However, when the hose was suspended above the plant and equipped with a sprinkler head so directed that the aerial parts were subjected to a continuous spray for one hour, a gain in weight of 16 pounds was noted.

Similar tests with Tank No. 8 were conducted on October 19 after additional asphalt had been applied and the seal tested. When the stream was applied to the aerial parts of the plant, a gain of 7 pounds was noted in the first hour, 9 pounds in the next 45 minutes and 6 pounds in the next 30 minutes, or a total gain of 22 pounds in 2 hours and 15 minutes.

A more conclusive demonstration was arranged on December 13. On this date the cover of Tank No. 10 was removed and soil samples taken from a vertical hole at three-inch intervals from the surface to the bottom of the tank. The surface of the soil was covered with oilcloth carefully cut to fit close to the edge of the tank and around the stool. Twenty-five pounds of technical plaster of Paris was spread over the oilcloth, making a layer about two inches thick. It was felt that a mechanical leak of water through the seal would be evidenced by the characteristic smooth surface-hardening of this material. The wooden cover was replaced, caulked and covered with the hot asphalt-resin mixture. A test of the efficacy of the seal after the manner described above showed no gain in weight which might be attributed to leak.

When the plant was sprinkled for four hours, a gain in weight of 71 pounds was noted.

Although the period from December 15 to 17 was one of high humidity and rainfall, the tank showed no further gain.

On removal of the top on December 17 the plaster of Paris was found to be uniformly hardened in a rough irregular surface as if it had hardened because of the saturated atmosphere in the tank. Two small spots, each about the size of a dime, were hardened with a smooth, slick surface as if a drop or two of liquid water had fallen on the light, fluffy surface prior to the general hardening.

Soil samples were again taken from a vertical hole driven into the soil at a point diametrically opposite the one previously used. Again three-inch increments were sampled.

Table VI gives the results of the two series of soil samples.

TABLE VI.

Moisture percentage at three-inch increments in Tank No. 10 before and after sprinkling.

Depth in Inches	Before Sprinkling	After Sprinkling
0-3	24.1	24.0
3-6	23.6	23.3
6-9	23.1	22.8
9-12	23.1	17.6
12-15	24.6	25.6
15-18	24.3	27.9
18-21	25.6	27.9
21-24	27.8	32.2
24-27	27.4	31.3
27-30	26.2	31.7
30-33	28.4	34.2
33-36	29.4	33.0
36-39	31.3	33.5
39-42	29.1	34.2
42-45	30.1	33.4
45-48	32.2	33.9
48-51	33.7	33.7
51-54	33.0	37.9

It would appear from these results that water had been admitted to the soil mass below the surface foot without wetting the surface foot. The evidence of the plaster of Paris seal supports this conclusion.

Interest in these results and a hope that these unsuspected physiological characteristics of the cane plant might be comprehensively studied, prompted the formation in April, 1930 of an Experiment Station project under the title "A Study of the Water Absorption Capacity of the Aerial Parts of the Cane Plant."

This project has contributed little to our present knowledge, although some progress was made as long as whole cane plants growing in soil under careful control were used. Some significant gains in weight were noted. The modification of the original plan involving primarily a study of the capacity of cane leaves to absorb water brought the project to an unofficial end in April, 1931.

Summary

This paper summarizes a long series of observations involving what appears to be an amazing capacity of the cane plant to absorb water through its aerial parts.

The problems involved are still unsolved and are of compelling scientific interest.

A current cooperative project involving the Experiment Station, H.S.P.A., and the Waialua Agricultural Company has recently added evidence to the general understanding. The comprehensive attack of this project needs additional information as to the physiological processes involved.

This note is prepared to summarize the evidence so far at hand and to suggest continued exploration in this new aspect of the water relations of sugar cane.

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Measures for the Control of *Anomala Orientalis* at the Oahu Sugar Company, Ltd.

By William Wolters

Introduction

Records show that *Anomala orientalis,* a native insect of Japan and Korea, gained entrance into the Territory of Hawaii some time prior to 1908 but that it was not definitely identified until 1912 when grubs were found damaging some of the cane fields of Honolulu Plantation Company, whence they spread to the fields of the Oahu Sugar Company. Anomala developed into such a serious pest that the trustees of the Hawaiian Sugar Planters' Association sent Dr. F. A. G. Muir in March of 1913 to the Orient, Java and the Philippines in search of enemies of the Anomala beetle. Several beneficial insects were brought to the Territory and released on the affected plantations. *Scolia manilae* was the only one that took hold and became established in the fields.* It was discovered in the Philippines by Dr. Muir in 1915 and shipments were made of this valuable parasite in 1916 and 1917. Scolia soon had Anomala under control as was shown by the reduced numbers and slow spread of the beetle, until about 1930 when Anomala outbreaks were again noted in some fields of the Oahu Sugar Company. Anomala infestation spread causing more and greater damage while Scolia seemed to have lost control of the situation. The Oahu Sugar Company, seeing this condition, proceeded to take immediate action in formulating measures of control.

* A second parasite *Tiphia segregata,* introduced from the Philippines in 1917 by Dr. F. X. Williams and liberated at Oahu Sugar Co., Ltd., has recently been found established.

Measures of Control

This paper is based on the work done at the Oahu Sugar Company over a period of three years in which the agricultural department of the plantation took an active part in conducting tests in the field. Many suggestions from members of the Experiment Station H.S.P.A., and others were tried out and we appreciate their contributions. Methods of control, technique of methods and results of our control measures are herewith discussed. Our control measures are classified as follows:

I. Soil Fumigants
II. Contact Insecticides
III. Electricity and X-Rays
IV. Stomach Poisons
V. Plowing and Fallowing
VI. Minor Control Methods
VII. Parasitic and Insectivorous Agencies

The above list embraces chemical, physical and natural control measures that have been used on the plantation. Unfortunately we have no practical way of determining in advance the presence of Anomala grubs in the soil. Anomala damage can be detected only after the cane is several months old at which time cane growth is checked, a slight yellowing of the leaves occurs and a weakened stool condition manifests itself.

Excavation studies were conducted systematically in order to determine the effectiveness of the various control measures.

Bi-monthly excavation schedules have been maintained on infested fields during plowing and preparation for planting.

The results of these studies have given us indications of the habits, spread, and intensity of infestation of Anomala under various soil and climatic conditions, as well as the amount of parasitism by Scolia. The grub counts obtained by these excavation studies indicate the time when it is safe to plant following a heavy infestation prior to plowing.

Check excavations were made from time to time in fields of growing cane where infestation was in progress or had previously occurred.

I. Soil Fumigants:

Soil fumigants may give temporary relief but do not protect the soil against renewed infestation. The more toxic fumigants are generally expensive and are both difficult and dangerous to handle. The less toxic and cheaper fumigants are generally ineffective and are more expensive in the end. Heavier applications of less toxic fumigants are necessary to equal the killing powers of the more toxic ones. The soil fumigants used in field tests are as follows:

(a) Chloropicrin
(b) Carbon bisulfide
(c) Paradichlorobenzene

(a) *Chloropicrin* is sealed as a liquid in steel cylinders. It is the most toxic of commercial fumigants and, in liquid form, has a specific gravity of 1.6. It vaporizes immediately on coming in contact with the air. It is most difficult and dangerous to handle, especially in cane fields where the air circulation is poor. The liquid is applied to the soil by means of special injectors to a depth of 8 inches. The treated area must be immediately sealed with a tar paper mulch in order to prevent the escape of gas from the soil. It is necessary for the operatives to wear gas masks and under such conditions they are only able to work for ten minutes at a time. It is slow, tediously disagreeable and expensive work.

The gas spreads in all directions from the point of injection, filling up the air spaces within the soil. The gas lasts about 36 hours when the soil surface is sealed with tar paper. The efficiency of the gas depends upon the amount applied and the texture and moisture content of the soil. We have obtained a maximum efficiency of 96 per cent kill under favorable conditions. It is too expensive for general use but serves its purpose where large colonies of grubs concentrated within a small area are to be eradicated immediately.

Experimental plots were laid out in an Anomala-infested area of a 6-month-old H 109 plant field. These plots received 100- and 200-pound applications per acre of chloropicrin with and without tar paper seals. The most effective kill was obtained in plots receiving 200 pounds per acre sealed with tar paper. Cane damaged by this gas does not fully recover. Two hundred pounds of chloropicrin per acre without the tar paper seal did the greatest damage to the cane. Results in terms of Anomala killed by the gas are shown in the table below:

Pounds Chloropicrin per Acre	Per cent Kill
100 pounds—no paper seal	33 per cent
100 pounds—plus paper seal	56 per cent
200 pounds—no paper seal	52 per cent
200 pounds—plus paper seal	68 per cent

There were several fields of 6-month-old H 109 ratoon cane with scattered patches of badly damaged cane that needed immediate action to check further spread of the damage. Judging from the results of the tests previously mentioned, it was decided to apply 200 pounds of chloropicrin per acre under a tar paper seal. We obtained a 50 per cent kill on two mauka fields which had a relatively compact soil and a 95 per cent kill on a makai soil of a more friable texture.

(b) *Carbon bisulfide* is sold in iron drums. It is a colorless inflammable liquid which is poisonous and has a strong, disagreeable odor. It volatilizes into a brownish vapor. It can be poured into holes made in the soil but it is best applied by means of injectors. Since the vapors are heavier than air, it is unnecessary to seal the soil surface. Ten times as much carbon bisulfide as chloropicrin must be applied in order to approach the killing power of the latter. One thousand pounds of carbon bisulfide per acre were used in the tests in a 6-month-old plant field and a 6-month-old ratoon field. An excavation study was made of the test in the plant field and we obtained a 50 per cent kill. There was no apparent damage done to the cane by the carbon bisulfide.

(c) *Paradichlorobenzene* is a crystalline, granular compound which slowly volatilizes in the soil. The vapor from it, being heavier than air, diffuses downward and outward through the soil mass when it is placed several inches below the soil surface. The material is easily handled and the vapor then given off is harmless to human beings. Its cost is about one-half that of carbon bisulfide and one-fourth that of chloropicrin.

Holes, 4 to 5 inches deep, are punched in the soil by means of a one-half inch rod and spaced 15 inches apart alternately on either side of the cane row. One-quarter to one-half ounce per hole gives an application of from 200 to 400 pounds per acre. The holes are plugged with soil. A week is necessary before any results can be expected since the crystal volatilizes so slowly. Action stops temporarily after an irrigation and begins again when favorable soil conditions return. Small test plots were placed in the relatively heavy soil of a mauka field and in the friable soil of a makai field.

This fumigant is used in Australia against soil insects and it is said to cause no injury to cane. This checks with our own experience. It is, however, ineffective against the Anomala grub as shown by the results from a test made on the looser soil type.

	Per Cent Kill	
Amount	10 Days After Application	20 Days After Application
200 pounds per acre	8.9 per cent	6.8 per cent
400 pounds per acre	6.2 per cent	5.5 per cent

II. Contact Insecticides:

We have found no contact insecticide that can be successfully used against the Anomala grub. We tried out two products, namely, (a) Derris or tuba root *(Derris elliptica)* and (b) Check Exterminator, a Chinese preparation.

(a) *Derris:* The following abstracts are taken from the U. S. Department of Agriculture, Washington, D. C., Miscellaneous Publication No. 120, April, 1923.

Derris is a genus of tropical plants comprising about 40 species . . . . Rotenone is the most important insecticidal constituent of *chinensis* and *elliptica*. As a rule, dried *Derris elliptica* root of good grade contains from 2.5 to 6 per cent rotenone . . . . It is insoluble in water, readily soluble in chloroform, benzene and acetone and slightly soluble in ether, alcohol and oils . . . . Rotenone is both a contact and stomach insecticide and promises to be effective against a wide variety of insect pests . . . .

We received a carton of powdered Derris root from Derris, Inc., New York City, which contained 4 per cent rotenone. Quoting from Marshall Dill's (Pacific Coast representative of Derris, Inc.) circular:

This type (Sarawak variety), which represents a toxicity of approximately 15 to 16 per cent Toxic Rosin, is the most efficient type of Derris in root form imported into the United States.

The following quotation is taken from an entomologist's report to Derris, Inc., dated November 13, 1933:

> The addition of Derris dust to the surface of the soil and watering would, I believe, not be very effective against any of these insects (Japanese beetle grubs and grubs of the taxus weevil). I also doubt very much whether it would be effective if it would be dug into the soil . . . . I believe, that Derris powder or its extracts would be of little use against grubs infesting any roots of sugar cane.

Commencing on December 14, 1932, we ran a test consisting of a series of three boxes containing six inches of soil each, into which we placed 50 medium-sized and 50 large-sized grubs to each box. Powdered Derris root was applied at the rate of 100, 150 and 200 pounds per acre respectively to the three boxes. The powder was worked into the top 2 inches of soil and a normal amount of water was applied. The boxes were screened to prevent outside infestation. Soil moisture was maintained at a normal figure. We examined the contents of the three boxes on February 20, 1933, after a run of two months. We were unable to determine definitely the mortality resulting from the treatments since many grubs probably completed their life cycle within the test period. We found three dead grubs, one in each box. Amount of application seems to have no bearing on the number of surviving grubs. There were 38 grubs in the 100-pound rate box, 43 grubs in the 150-pound rate box and 66 grubs in the 200-pound rate box.

(b) *Check Exterminator* is a combination contact insecticide and weak fumigant manufactured by Look Teong Kee of Honolulu. This insect exterminator has been successfully used on golf greens throughout Oahu against sowbugs, earthworms, etc. The manufacturer's agents asked permission to try out their product for killing Anomala grubs. We cooperated with them in some laboratory and field experiments. The first exterminator used was the type that drives insects out of the ground, similar to the kind used on golf greens, but it did not work on the grubs. This brand of exterminator was replaced by their most powerful Check Exterminator which was supposed to kill insects in place. This was used in the experiments described below.

Three one-line plots were placed alternately down a watercourse in an area badly damaged by Anomala. The plots were filled with irrigation water and while still full, Check Exterminator was sprinkled over the water at the rate of 6,000 pounds per acre. The water was vigorously agitated to get a uniform solution which was allowed to percolate into the soil. Excavations showed that the exterminator reached a depth of 18 inches below the bottom of the furrow, as indicated by the fumes in the soil. It did not penetrate the hard subsoil. Excavations were made from 5-foot sections of line equivalent to 25 square feet to a depth of 18 inches at intervals of 1 day, 2 days, 3 days, 1 week, 2 weeks and 4 weeks after application.

	Per Cent Kill for Each Period					
Intervals:	1 Day	2 Days	3 Days	1 Week	2 Weeks	4 Weeks
	0	0	6.2	4.8	0	0

The results show a very low per cent of kill, if we could prove to ourselves that the Check Exterminator really did kill the grubs.

This test was repeated under controlled conditions, using a wooden box 12 inches square and 18 inches deep. Ten large, healthy grubs were placed in each of three, six-inch layers of soil partitioned off by fine-mesh wire screens. Check Exterminator was applied in solution at the rate of 6,000 pounds per acre. Normal soil moisture was maintained. After 7 days the soil was removed and the grubs examined, but we recorded no mortality. We can safely conclude the Check Exterminator is of no avail and the price would not need to be considered.

III. Electricity and X-Rays:

An experiment was made to determine the effect of electricity on Anomala grubs. We wanted to find out whether grubs could be killed in the soil by electricity, since we had the opportunity of using an electric plow owned by one of the pineapple companies.

Grubs were exposed directly to the intense electric arc created by an A. C. current of low amperage and high voltage and died from the effect of burns. Then grubs were placed in a layer of moist soil (necessary to conduct a current) about two inches thick. One electrode was placed below the soil and one above the soil and an A. C. low amperage-high voltage current (varying from 10,000 to 25,000 volts) was passed through the soil. As long as the grubs remained within the soil they did not seem to be injured by the current, but as soon as they came in direct contact with the arc, they were burned by it. Our chief electrician coöperated by conducting the electrical phase of the test. These tests were repeated a number of times with the aforesaid results. The impossibility of deep penetration into the soil by an electric current apparently eliminates any ideas of practical field operation with the apparatus available at present.

It seemed a bit far fetched to consider X-rays as a possible means of killing grubs, but an experiment was made, nevertheless. Several large grubs were subjected to X-rays at full strength for two minutes which was the time limit in order to avoid strain on the X-ray tube. They became extremely antagonistical within five minutes after the exposure and proceeded to fight each other. They were alive several days later and seemed none the worse for their treatment.

IV. Stomach Poisons:

Lead arsenate, white arsenic and Derris root were the only materials under the above classification considered worthy of more extensive experimentation. Lead arsenate was used in the earlier experiments, and in the first lot of mud press-arsenic traps which are described later. The high cost of this material made its use on a field scale too expensive.

Derris has already been discussed under *Contact Insecticides* (a).

White arsenic (As_2O_3) was finally selected as offering the greatest promise of success and has been used in a number of ways. It is fully as effective as lead arsenate, and is far less costly. It is easily and firmly fixed by the soil and does not noticeably injure the cane, even after heavy applications to the soil. It is evidently effective for several crops since it does not leach out, which has been shown by soil analyses two years after an application. Care must be taken to protect the men handling it due to its poisonous composition. Whenever opera-

tives apply arsenic, they are required to wear standard respirators and to wash their hands thoroughly before eating and at the end of the day. It is the most effective chemical agency we have in the artificial control of Anomala from an economic standpoint. The arsenic program may be divided into the following phases of application:

(1) Mud Press-Arsenic Traps
(2) Broadcast in the Cane Furrows
  a. Mixed with mud press
  b. Alone
  c. Mixed with fertilizer
(3) Plowed into the Soil
  a. Alone
  b. Mixed with mud press
  c. Mixed with fertilizer
(4) Application of Mud Press-Arsenic Mixture to Ratoon Cane
(5) Application in Waterways

(1) *Mud Press-Arsenic Traps:*

Traps consisting of mud press sprinkled with arsenic, or mixed with it, were set out in piles along the edges of fields exposed to Anomala-infested areas. Mud press has a great attraction for the beetles as a material in which to lay eggs, and the young grubs feeding on the mud press are killed by the arsenic.

The first mixture was in the proportion of one ton of mud press to 100 pounds of lead arsenate. Shallow holes were dug six feet apart along the edges of two fields of one-year cane adjacent to, and on the leeward side of, two Anomala-infested fields which were being plowed. The traps were set out January 13, 1932, and a year later they were still intact and arsenic was present. C. E. Pemberton of the H.S.P.A. Experiment Station made periodic examinations of these traps but never found any live grubs in them although dead beetles were found from time to time, showing that they must have been active. Trials of arsenic treatments were extended gradually until we felt sure that they were producing results. More fields, similarly exposed, were treated in the same manner, but white arsenic was used in the mixture. These traps were set out as an insurance against possible infestation of the unaffected areas.

(2) *Broadcast in the Cane Furrows*—(a) *Mixed with Mud Press:*

The application of arsenic was continued on a larger scale and it was broadcast over the entire furrow.

Our first experience was in a field of 4-month-old plant cane. The Anomala grubs were doing considerable damage in scattered patches throughout a portion of the field. Light applications of arsenic, followed by a light blanket of mud press, with a second dressing of arsenic on top of the mud press, were made over the entire furrow in the infested spots. The grubs which were already in the soil probably were not affected by this treatment, but we felt certain that any new infestation would be greatly reduced as a result of the young grubs feeding

on arsenic-treated mud press. This method, however, is comparatively slow and relatively expensive for a general practice, and can be used only when mud press is available at the mill. The cane which had been damaged by the Anomala did not fully recover, but it improved a great deal as a result of the treatment. The field was harvested in March, 1934, and there is little or no evidence of Anomala damage in the first ratoon.

(2) *Broadcast in the Cane Furrow*—(b) *Alone:*

In a field of growing cane, it was found to be more feasible to broadcast white arsenic alone to the cane furrows or kokuas because of the cost of application of the mud press-arsenic mixture. Due to the nature of white arsenic, it was difficult to apply it in quantities less than 200 pounds per acre even when working under the best conditions. It is difficult to estimate the rate of application when arsenic is broadcast over furrows and kokuas in scattered and irregular patches.

One damaged field was treated by the above method in 1932 and four damaged fields in 1933. The damaged fields in 1934 were too heavily infested for the use of this spot method, and were plowed up.

When the infestation exceeds the limit of economical control by the spot method, then it becomes necessary to plow the entire field a number of times, during a fallow of several months' duration in order to eliminate Anomala (See V. *Plowing and Fallowing.*)

(2) *Broadcast in the Cane Furrow*—(c) *Mixed with Fertilizer:*

It was felt that ratoon fields showing indications of light Anomala infestation would benefit by a light application of arsenic to the entire field. It is impossible to make accurate applications of less than 300 pounds per acre in growing cane so as to cover the entire line, and this amount of arsenic per acre is more than is required under these conditions. Scolia do not seem to operate in cane after it is well closed in, but Anomala continue to operate. Arsenic would protect the field after Scolia ceased to function. Therefore, a method was sought by which white arsenic could be applied economically and in light amounts. This has been accomplished by mixing it with any dry fertilizer normally applied to the field. The Pacific Guano and Fertilizer Company makes arsenic-bearing mixtures according to requirements. The amount of arsenic applied per acre depends upon the fertilizer-arsenic mixture and the rate of fertilizer application. Fertilizer is applied in one application or in split applications to suit conditions. The men are protected with respirators and necessary precautions are taken in handling the mixture. The fertilizer-arsenic mixture is broadcast over the lines by hand. By applying arsenic in this manner, the rate of application is more uniform and there is a saving in the cost of the work. Several fields have received this treatment and the cane is in excellent condition with no outbreaks of Anomala.

(3) *Plowed Into the Soil*—(a) *Alone:*

One of our upland fields (Field "A")* was infested with Anomala grubs to

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*** For the purpose of this paper, certain fields are designated as "A", "B", "C", and "D".**

the extent of making it necessary to plow. It was decided to try out a heavy application of arsenic plowed into the soil at the rate of one ton per acre. Three, one-third-acre plots were selected in parts of the field which had suffered the greatest damage. Prior to the application of arsenic, the field had been disc-plowed twice, deep-plowed once and disc-harrowed once. The three plots were disc-plowed twice and disc-harrowed once after the arsenic application. The arsenic was broadcast by hand on March 18 and the plots were planted on March 31, 1932. They received normal plantation cultivation, fertilization and irrigation.

This experiment is exceedingly interesting because we can closely follow up the effect of large quantities of arsenic on soil population, cane growth and yields over a long period of time. The first excavation and grub count to determine the effect of arsenic was made six months after application. One hundred square feet were excavated from each of the treated and untreated areas to include the kokuas and bottoms of the lines to a depth of 12 inches below the bottoms of lines. The results of this excavation showed an average difference of 87 per cent in Anomala grub population in the soil in favor of the arsenic treatment.

Excavation studies were made 25 months after the arsenic application to determine the continued effectiveness of arsenic on grubs. The field, meanwhile, had been harvested and ratooned. Excavations were made to a depth of 20 inches below the bottoms of the furrows and all grubs and insects present in the soil were counted. The greatest numbers of both, including Anomala in all stages of development, were found in the 0 to 10-inch layer followed by the second largest number in the kokuas and the smallest number in the 10- to 20-inch layer. There were 91 per cent less Anomala grubs in all stages in the arsenic plots.

We observed the effect of this heavy amount of arsenic on cane growth and color from time to time. The growth seemed about the same for the unaffected stools of cane in either plot. There were times when we thought the cane was greener in the arsenic plots but this may have been due to healthier growth. There was a noticeable difference in the stand of cane and at harvest time, at the age of 23.7 months, the arsenic plots outyielded the check plots by 10.16 tons of cane, equivalent to a 12 per cent increase.

(3) *Plowed Into the Soil*—(b) *Mixed with Mud Press:*

It is usually found that repeated plowing and harrowing during a fallow period of three to six months will practically eliminate Anomala from a heavily infested field. However, the grubs will sometimes persist despite this treatment, and arsenic treatment over a relatively large area becomes necessary.

Hand mixing mud press and arsenic for any large area is economically out of the question. Broadcasting in the open field is not to be recommended from the standpoint of the health of the men and also because it is impossible to make a uniform application, due to the nature of the compound. The cheapest and most feasible method is to mix the arsenic with the mud press and apply it mechanically. This is done as follows: In order to mix these materials, a platform was built over the mud press conveyor which is *outside* of the mill and fully protected to prevent escape of arsenic dust. A mechanical fertilizer-hopper was set up on the platform and a feed pipe was dropped from the hopper into the conveyor.

Mechanical drive is furnished by the shaft of the screw-conveyor. The arsenic flow is regulated by a feed control. It takes the mud press ten minutes to travel from the arsenic hopper to the discharge of the conveyor trough into the mud press car. The screw-conveyor gives the mud press and arsenic a thorough mixing during this period of time. This mixture is hauled to the fields in mud press cars and reloaded into mud press spreaders. After the mud press-arsenic mix has been applied to the field, it is plowed and harrowed into the soil a number of times to insure proper incorporation with the soil.

A 21.94-acre area in Field "B" was the first place to receive this treatment. Periodic excavations in this area had shown very large numbers of grubs in all stages of development and these numbers had been maintained despite climatic effects, stages of development and the effects of plowing. The chosen area represented the most heavily infested part of the field. It was disc-plowed and disc-harrowed once before the mud press-arsenic mix was applied February 14 to 28, 1934, at the rate of 44 tons of wet mud press per acre or 365 pounds of arsenic per acre. It was then disc-plowed twice, disc-harrowed once, deep-plowed once and disc-harrowed again in the order named. It was machine-planted in August, 1934, after being given a comparatively clean bill of health as to Anomala. The arsenic did not entirely eradicate the grubs but it definitely reduced the infestation, in comparison with the untreated portion of the field, to the point of control by parasites. The results of the excavations made between the time of application of the mixture and time of planting are shown below:

SMALL, MEDIUM AND LARGE GRUBS—TOTAL PER ACRE

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 2 Mud Press Only	Plot 3 Mud Press-Arsenic	Per Cent Decrease
6/23/34	1,685,385	11,323	99.3
7/ 6/34	648,024	4,355	99.3
7/19/34	298,753	34,840	88.5
8/10/34	178,555	11,323	93.7

The high count of grubs shown under Plot 2 for June 23 consisted chiefly of very young grubs recently hatched before the excavation was made. The above data illustrate clearly that mud press is attractive to the Anomala beetle, an ideal medium for incubation and a perfect feeding ground for the young grubs.

Eighty-four per cent of the area of Field "C" received the mud press-arsenic treatment at the rate of 38 tons of mud press per acre or 314 pounds of arsenic per acre. Prior to this treatment the field was disc-plowed twice and disc-harrowed once. This mixture was applied April 16 to May 18 and from May 26 to June 2, 1934. The field was then disc-plowed once, disc-harrowed once, deep-plowed once and planted in August, 1934. The effectiveness of arsenic is indicated by the results of the excavation data shown below:

SMALL, MEDIUM AND LARGE GRUBS—TOTAL PER ACRE

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 3	Plot 4	Plot 5	
2/15/34	209,040	279,591	177,684	No
3/ 3/34	181,168	58,357	54,873	Treatment
3/19/34	162,877	94,068	111,488	Average of
4/10/34	106,262	185,523	148,941	3 Plots
5/ 2/34	229,944	54,873	181,168	
5/11/34	120,198	160,264	180,297	155,368

SMALL, MEDIUM AND LARGE GRUBS—TOTAL PER ACRE

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date of Excavation	Plot 3	Plot 4	Plot 5	
5/26-6/2 Application of Mud Press-Arsenic Mix				
6/19/34	70,551	47,034	86,229	Mud Press-Arsenic
7/ 2/34	21,775	62,712	44,421	Treatment
7/19/34	5,226	15,678	64,454	Average of
7/23/34	7,839	33,098	39,195	3 Plots
8/ 9/34	27,001	19,162	28,743	40,414

Results from periodic excavations indicate the trend of infestation under many field conditions and their respective treatments. We find a greater number of grubs in field areas treated with mud press alone than in those areas which have received no mud press and we find the least number of grubs in the field areas which have had the mud press-arsenic treatment. The above table shows an average of grubs equal to 155,368 for the three plots over a period of six excavations *prior* to the mud press-arsenic treatment. The average figure for the three plots over a period of five excavations *after* the mud press-arsenic treatment is 40,414 or a decrease of 74.0 per cent.

(3) *Plowed Into the Soil*—(c) *Mixed with Fertilizer:*

Another method of applying the fertilizer-arsenic mixture (See *Broadcast in the Cane Furrow*—c) to fields having light infestation of Anomala is by means of our subsoiler-fertilizer machine. It deposits the mixture to an average depth of 9 inches next to the root system where it is immediately effective. Subsequent irrigations disperse the mixture a little further into the soil mass and in closer contact with the grubs. This method of application saves the full labor cost necessary when applying the mixture by hand. No extra labor is needed on the subsoiler-fertilizing machine. We tried out this method in comparison with the surface application of the fertilizer-arsenic mixture. In both cases, the cane in the fields so treated seem not to be further damaged by Anomala. An explanation

is offered to the effect that when surface applications are made, the newly hatched and young grubs are killed by the arsenic near the surface; whereas, by the underground method, the young grubs on becoming more mature go deeper into the ground in their search for live cane roots, come in contact with the arsenic within the soil, which results in their death. This was just another method of arsenic application as a means of insurance against a heavier infestation.

(4) *Application of Mud Press-Arsenic Mixture to Ratoon Cane:*

The mud press-arsenic mixture from the mill is railroaded to the field and dumped near an irrigation ditch. It is fed into the irrigation ditches by men with shovels and, in this way, it is sluiced into the field by the irrigators. A blanket of finely divided mud press and arsenic is deposited in the furrows. The rate of application depends upon the area irrigated within a period of time, the amount of water used and the speed and number of men feeding the mix into the ditch.

Field "D" had a light infestation and was treated in the above manner. It is difficult to put on a uniform application, especially if there are only one or two dumping sites. We decided to put on a 200-pound application of arsenic per acre but it worked out that we had a larger amount near the dumping site and about a 50-pound application at a place in the field farthest removed from the dumping site. The more dumping sites there are, the better will be the control over the uniformity of application, but there are usually practical limitations to the number. The grubs that are already in the soil would not be affected by this treatment but it would reduce new infestation.

(5) *Application in Waterways:*

Waterways, such as level ditches, have bottoms of fine soft, loose soil which become attractive places in which the Anomala beetles lay their eggs. After a field has received an application of mud press sluiced in by water, there is, in addition, a layer of finely divided mud press which is deposited in the ditch and becomes even more attractive to the beetles. Thus we sometimes find the beginning of what promises to be a heavy infestation and in order to check this, we have applied arsenic in the ditches. It is then worked into the mud press and soil to a depth of several inches so as not to disturb the ditch too much. This method has proven to be effective as shown by examinations made from time to time on the checkup of grubs present in the ditches.

V. Plowing and Fallowing:

When a field becomes so badly infested with Anomala grubs that chemical measures become economically prohibitive, then the only solution is to plow and fallow until the grubs have disappeared or until the numbers are small enough to be kept under control by the natural parasites. Frequent plowing tends to keep the soil aerated and dry which aids greatly in keeping down infestation. This is particularly true during wet periods when Anomala grubs thrive in the soil. The grubs do not thrive so well in hot weather and go down deeper into the soil to avoid the dry, upper surface. As they go down deeper into the soil, there are less roots to feed on and they probably do not develop very fast. Heat and dry soil

are most detrimental to the newly hatched grubs which hatch near the surface of the soil. Anomala grubs travel deeper into the soil as they become more mature and are exceedingly active around stools of cane where they feed on live roots.

One or two disc-harrowings will spell death to most of the newly hatched and immature grubs while a disc-plowing will get many of the more mature grubs. Plowing exposes the grubs to the heat, birds and particularly the ants which attack them furiously. Ants are a very good agent in destroying grubs but they can operate only when the soil has been stirred up.

The knowledge of when to plow is greatly aided by the results of periodic excavations. It has been the practice here to establish numerous excavation areas scattered throughout the field in which excavations are made at bi-monthly and weekly intervals, depending upon conditions. There is a great variation in infestation over a field, which is clearly shown by the results in the table below. The effect on Anomala grubs of frequent plowing is also indicated by the same data. The data have been taken from excavations made in Field "D" which has received no treatment in the nature of molasses or mud press.

Small, Medium and Large Grubs—Total Per Acre

(As estimated from the number of grubs found in the excavated plots of 50 square feet.)

Date	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Average
1/24/34	31,356	95,810	462,501	19,162	1,742	209,040	219,492	148,443
Field was disc-plowed and disc-harrowed.								
2/28/34	30,485	85,358	385,369	1,742	0	16,549	63,583	83,298
3/15/34	35,711	45,292	155,038	0	1,742	31,356	90,584	51,389
Field was disc-plowed a second time.								
4/ 4/34	21,775	116,714	21,775	2,613	0	28,743	53,131	34,964
Field was disc-harrowed a second time.								
4/17/34	48,776	56,615	8,710	3,484	0	2,613	16,549	19,535

VI. Minor Control Methods:

The determination of the plantation to suppress the Anomala has been indicated by many kinds of control measures already described. An attempt has been made to leave nothing undone which gave reasonable promise of economical results. Anomala beetles and grubs have been destroyed by every practicable means. Mr. Pemberton, upon dissecting a number of beetles caught on flowers during flight found that a large proportion were females containing some unlaid eggs.

Anomala beetles enjoy feeding on the fuzzy flowers of paper bark trees, haole koa and the klu bush and can be easily caught. It is not worth while collecting the comparatively few from this source since these plants are not always in bloom and are found growing only in our waste lands. But, a plant of the genus

Ageratum having a small, fuzzy florescence grows about two feet tall, blooms all year and is especially attractive to the beetles. The plants are hardy and freely reseed themselves. These flowers were planted particularly in and around Anomala districts. The plants were set out along the ditches, roadways and edges of fields. Collectors received worthwhile remuneration for each bottle of beetles caught and, as they are easily caught while feeding on the flowers, large numbers were collected during flight periods.

During the first plowing operations when the grubs were most numerous, workers followed the plows to pick up Anomala grubs. An individual would average several thousand a day in heavily infested areas. They were paid by the number they picked up during the day.

Mynah birds did their duty toward the cause. They followed the plows around the field much like sea birds follow a ship at sea and probably consumed a great many grubs per day. They seemed to be fatter at the end of the day.

Flowering plants and certain kinds of weeds, the florescence of which is favored by the Scolia wasp for feeding purposes, are allowed to grow on roadsides, ditch banks, etc., throughout the fields of the plantation. Certain garden flowers have been planted along supply ditches and Mexican creeper along reservoir banks. An ample supply of favorite food promotes widespread population of the parasites.

VII. Parasitic and Insectivorous Agencies:

Scolia manilae has been the only parasite which has successfully controlled the Anomala, which it did until the last few years when Anomala got ahead of it on some parts of the plantation. It seems that there is a definite climatic effect on the relationship of Scolia development to Anomala development. This was particularly observed within the last year or so. The Anomala bred, developed and thrived during the cold, wet spell at the beginning of the year, while Scolia became scarce. For a period of six months Scolia was exceedingly rare.

A new parasite, called Elis and similar to Scolia in habits and structure, has been imported into the Territory from Guatemala by the entomologists of the Experiment Station. There are several species of which *Elis near pulchrina* is the largest importation. The first release of *Elis near pulchrina* was made on August 14, 1934, to one of our centrally elevated fields and further releases were made to a mauka and makai field where Anomala grubs are certain to be present in the soil.

A number of Tiphia parasites, also similar to Scolia, were released to one of our mauka fields in August, 1934.

Another beneficial insect has been imported by the Experiment Station. It is a large, predatory wireworm, of the genus Pyrophorus, which feeds upon grubs in the soil. The first shipment of these wireworms was received from Guatemala by the Experiment Station on June 4, 1934. The larvae will be developed to maturity in their laboratory, the adults will be mated and liberated to our fields.

The first release of the giant, tropical American toad, *Bufo marinus,* which was imported into the Territory from Puerto Rico in April, 1932, was made on August 18, 1933, to one of our reservoirs and to date we have liberated toads to all of

our reservoirs. The young ones eat ants and other small insects while the mature toads will eat almost any insect which will come to their vision. They are expected to do a great deal of good, not only with respect to Anomala control but also for other crops, vegetables and flowering plants. They are said to be nocturnal, generally hiding by day. They are beginning to spread through the cane fields and the larger ones are more in evidence.

Summary and Conclusion

Every effort has been made, in conjunction with the staff of the Experiment Station, to develop practical and economical measures for the control of Anomala, while awaiting the introduction of a parasite more effective than Scolia. A considerable degree of success has been attained.

The summary and conclusions are as follows:

1. Soil fumigants proved to be impractical and uneconomic.
2. Contact insecticides could not be properly dispersed in the soil mass and were not toxic to Anomala grubs.
3. Electricity was ineffective and commercially impractical. X-rays were experimented with merely to determine their effect on grubs.
4. Stomach poisons, particularly white arsenic, were the most successful of the chemical agencies. A technique for the application of white arsenic under various conditions was developed and the results have been satisfactory.
5. Plowing and fallowing are resorted to when natural control has failed, and chemical control becomes economically prohibitive.
6. Anomala beetles and grubs were collected and destroyed.
7. Parasites and insectivora can provide natural control. Scolia has failed at times when it was most needed. New parasites, similar to Scolia, have been imported into the Territory for Anomala control. A large, predatory, Guatemalan wireworm has been imported but not yet released. The giant American toad, *Bufo marinus,* is becoming established on the plantation. These new importations are expected to do a great deal toward keeping Anomala in check.
8. The Anomala grub is a difficult pest to eradicate, and there is much still to be learned about its life habits in the cane field under various conditions throughout the year.
9. The Anomala beetle is a prolific breeder. Its habits of flight are such that infestations are localized, and may occur at relatively widely separated points.
10. The life cycle of the Anomala is comparatively short and the grubs are ravenous eaters and do considerable damage in a short space of time.
11. The presence of Anomala grubs in the soil may not be known until indicated by the damage to cane growth, weak stools of cane and a peculiar yellow color of the leaves. Scattered patches of Anomala infestation can develop into large areas of such severe infestation as to necessitate plowing out a field.

Acknowledgment is hereby made of the cooperation of the plantation staff, and the staff of the Experiment Station in all of the work reported herein.

The writer is indebted to E. W. Greene for his helpful suggestions in the preparation of this paper.

Predisposing Factors in *Pythium* Root Rot

VII

By C. W. Carpenter

This paper, the seventh of a series on *Pythium* root rot and growth failure of sugar cane is a synthesis of observations made in Hawaii during the last four years. The related material in a considerable number of separate investigations, and cooperative endeavors with various members of the staff, is combined to show the present status of the research. The positive objective of crop improvement through an understanding of the causes of root failure and the practical aspects of the separate problems studied have determined the mode of procedure. The information gained from research now permits the assemblage of many fragmentary and seemingly contradictory details into a logical sequence to reveal the simple components of a problem utterly complex when considered in its entirety.

The environmental factors, which modify the susceptibility of the roots to the attacks of the fungus, *Pythium* sp.*, have been the chief concern. The experiments and observations are a further elaboration of the thesis (10, 13) that the susceptibility of cane roots not only varies with the varieties of cane but that within the variety susceptibility or resistance varies with the nutrition. The relation of excessive nitrogen fertilization, with respect to a particular variety, to increased susceptibility to *Pythium* root rot has been discussed in other papers of this series (10, 11, 12, 15). More recently, Cooke (20) and the writer have demonstrated that *Pythium* root rot is an important accessory in the growth failure of standard varieties over considerable areas of soil deficient in available phosphate. These soils are characterized by the Chemistry Department as "phosphate-fixing" soils. Observations indicate that with root susceptibility present, either the natural weakness peculiar to certain varieties or the susceptibility acquired by the naturally more resistant commercial varieties following malnutrition, the degree of rotting is vastly influenced by soil temperature and moisture. Various investigators (23, 25, 27, 28) have not failed to recognize the importance of soil temperature and moisture in *Pythium* root diseases.

It will be noticed that as the investigations of root rot and growth failure continue, *Pythium* root disease is demonstrated to be a larger factor in cane culture than was formerly realized. The literature of the past decade, reviewed herein to trace the progress of research, shows an increasing recognition of the relation of *Pythium* sp. to the etiology, not only of sugar cane root rot, but also of many obscure diseases of various crops. It is a matter of common knowledge in Hawaii that the Lahaina variety of cane failed over large areas and became gradually so undependable as a result of "root rot" that it was finally eliminated from our cultures. Coincidentally, the experience with Lahaina has been repeated on a smaller

***Pythium* sp. heretofore referred to as *Pythium aphanidermatum,* will be referred to henceforth as *Pythium graminicolum* (see p. 288).**

scale with several other varieties which have been tried and largely discarded. *Pythium* root rot was more recently identified as a serious hazard in the early stages of cane seedling propagation. Various seedlings which have been selected and planted in spreading areas in the field also have failed each season from *Pythium* root rot. Certain seedlings have been observed to fail in one locality only while being very promising in others.

The marked improvement of cane growth in steamed or chemically fumigated soil has been a collateral subject of further investigation in relation to the general problem. H. P. Agee, Director of this Station, suggested that root-pruning parasites might be universally active in our commercial fields and that the growth improvement and the development of characteristically abundant masses of fine rootlets in steamed soil might be the result of the elimination of such root parasites. Potentially, this question was of basic importance and required thorough investigation. The investigations of the nature of plant response to sterilized or fumigated soils served later as a basis for cooperative experiments with Cooke (20) and the detection of the relation of *Pythium* root rot to growth failure in phosphate-fixing soils. The experiments reported herein indicate that the increased growth in sterilized soils is not, in general, due to the suppression of parasites but that it is largely a response to stimulative nutrients rendered available in larger amounts as a result of the treatment.

The subject matter of this paper which includes somewhat diverse phases of the general problem is conveniently presented under the following captions: "Review of Literature"; "Improvement of Cane Growth in Steamed or Fumigated Soils"; "Abnormal Nutrition as a Factor in *Pythium* Root Rot." The review of the literature, while by no means complete, is intended to include enough citations to sketch the trend of the investigation of root rot of cane and other grasses for the period under survey—1919 to date. Certain papers, not included in this review, are more appropriately cited in the section particularly concerned.

Review of Literature

Species of the genus *Pythium* have been reported during the past decade by various investigators in several countries not only as causes of root rot of cane, confirming the writer's (5) observations in 1919, but also of several other crops. Among the latter, the root rots and growth failures of the cereal crops, corn and wheat, are noteworthy as corresponding more closely with cane root rot.

In Puerto Rico, Matz (39) mentioned *Pythium* sp. and *Rhizoctonia* sp. as being isolated and considered as possible causes of cane root rot. His experiments apparently led him to consider the latter group of fungi more significant. Bourne (3), in the same country, presented evidence from his observations and stated that the *Pythium* associated with root rot in Puerto Rico was morphologically identical with that reported in Hawaii (foot note l.c. p. 63). As a result of earlier studies in Barbados, Bourne (2) reported *Rhizoctonia* sp. as active causes of root rot.

Lyon (35) reviewed the status of the root-rot problem from 1895 to 1923, citing the important investigations. The reader is referred to this review and critical appraisal of the significance of the various theories and the evidence pre-

sented in their support. His citation of Hoffer and Carr's (30) investigations of corn root rot and the quotations therefrom regarding the relation of aluminum in acid soils and deficiencies of lime and phosphate to the disease, is particularly interesting in view of subsequent observations of a direct relationship of deficiencies of lime and phosphate to *Pythium* root rot of cane in Hawaii (20, 37). We quote the entire summary by Hoffer and Carr as of special significance at this stage in our progress of fitting together the complex interdependent factors in the *Pythium* root rot complex:

(1) One of the most characteristic differences between normally growing corn plants and those which become severely rootrotted is the condition of the vascular plate tissues in the nodes of the stalks. The plants which become severely rootrotted are those which have the nodal tissues discolored and in various stages of disintegration.

(2) This disintegration of the nodal plate tissues begins in the absence of any specific organisms in the tissues.

(3) The brown, yellowish brown, and brownish purple discolorations with their consequent disintegrations which are frequently found in diseased plants have been produced artificially by injecting solutions of certain salts of aluminum and iron into the plants. Definite chlorophyll and leaf-tissue changes have been produced also. Other factors, however, may operate to produce similar effects.

(4) These artificially induced changes in the plant parts closely resemble the phenomena which develop in plants growing in the field under conditions favorable to rootrots.

(5) The most severe cases of rootrots have been found in soils notable because of their deficiencies of lime and available phosphates.

(6) Such soils have variable quantities of salts of aluminum and iron available for absorption by plants.

(7) Corn plants show marked differences in the quantities of aluminum and iron salts which are absorbed by them. These differences develop when the salts are available in subtoxic concentrations in the soil and are believed to be due to specific selective capacities of different plants to absorb the available aluminum and iron salts from the soil. This type of selective absorption cannot operate when the aluminum and iron salts occur in quantities which are toxic to the roots.

(8) A definite cumulative toxicity of aluminum salts within the plants was established by the injection experiments, and it is believed that the same phenomenon occurs naturally in the field. The relative quantities of the available metals and of nitrates in the soil determine, in a large measure, the rate of development of the cumulative toxicity of the metals within the plants. Those plants which contain the largest quantities of these metals are the ones which seem to develop the most severe cases of rootrots when the organisms are present in the soil and the meteorological conditions favor their optimum growth.

(9) When abundant aluminum injuries occur in the corn plants in certain fields it is an indication that the soil is deficient in available phosphates.

(10) The application of lime and phosphates to soils in which rootrots have developed in destructive proportions has been decidedly beneficial in controlling them. The use of limestone alone in some instances proved harmful, but in all cases studied so far the application of available phosphates produced plants which were better and more resistant to the rootrots.

McGeorge (40, p. 322) pointed out that the more resistant varieties of cane had shown evidence of root rot in our upland soils, which differ from lowland soils in being more acid, a feature accompanied by phosphate, and occasional potash, deficiencies. He mentioned that a number of investigators in soil fertility studies including those in Indiana, Massachusetts, New Jersey, Rhode Island and the Bureau of Plant Industry, U. S. Department of Agriculture, had reported salts of iron, aluminum and manganese associated with the low root vitality of

crops grown in acid soils. McGeorge stated that he had found the same abnormal characteristics in stalks of cane that Hoffer reported in corn and that the toxicity of aluminum salts had been demonstrated. He (41, p. 468) also reviewed Hoffer's studies accompanying the citations therefrom with references to observations in Hawaii.

Stewart (50) discussed growth failure of H 109 in mauka (upland) fields on the island of Oahu, which was corrected by additional fertilization and extra irrigation. The following paragraphs are quoted from his report:

Further interest, in the composition of the Oahu soils, was aroused during the past year by the behavior of H 109 cane in Field 20. A number of poor spots appeared in portions of this field where the cane seemed to be affected by root rot. Soil samples were collected from these poor spots and from adjoining land where good cane was growing. The majority of the samples from both the good and poor areas were low in available phosphates and contained a minimum quantity of available potash. The total potash supply was excellent, but the total phosphates were distinctly low for Island soils.

A definite connection has been shown recently in the Eastern United States, between deficiencies of available phosphates and potash and the occurrence of root rot in corn crops. This trouble has been found, usually, on very acid soils where toxic salts of soluble aluminum and iron are present. Such soils are found in these Islands in the mauka lands of the unirrigated plantations. At the same time, there is considerable indication that plant food deficiencies may contribute to root troubles in soils that are not notably acid. It seemed desirable, therefore, to make a more general survey of the Oahu Sugar Company lands.

The results of this work showed that most of the areas which were low in available plant food were located in the mauka fields, but that Field 20 was largely low in phosphate content. Further field experiments with phosphates and potash were recommended. It was concluded that the appearance of root rot in Field 20 was due to a deficiency of plant food and a poor water-holding capacity in the soil of limited areas. The affected cane was given additional fertilization and extra irrigation and has now recovered completely.

Naquin (42) has suggested the relation of a deficiency of potash to a form of root rot at Honokaa Sugar Company, the symptoms being similar to those of Lahaina failure. He reported his observations, in part, as follows:

Recently a case of acute potash deficiency occurred in a kuleana where cane was planted for the first time four years ago. This was D 1135, and the symptoms were noticed about 6 months after the cane had been cut, and when the young cane was growing vigorously and there was an excessive amount of cane per linear foot. Gradually the symptoms developed and spread, so that the whole area was affected in different degrees of acuteness.

Field tests were started 3 months ago, when applications were made of nitrate, 200 lbs. active ingredients per acre, potash 400 lbs. and phosphate 400 lbs. per acre.

The cane where potash was applied immediately picked up and started a new growth, and cane which had reached the size of a lead pencil and had only a few leaves immediately increased the number of leaves and gained in girth. Three months after the application of potash all of the plants were growing normally.

In cases where nitrate and phosphate were applied the conditions were more or less aggravated, and most of the cane died out and a secondary crop of suckers is coming out at present.

This condition, as well as other similar conditions, which have occurred in small patches here and there on the plantation have been studied and diagnosed by different investigators as root rot. McGeorge, in Bulletin 49, of the H.S.P.A., cited one of the areas as being deficient in potash, and found in pot cultures that the root of the cane was stimulated by potash application. From this it must not be assumed, however, that all soils which respond to potash show symptoms of root rot. It is only the acute stage of potash deficiency that produces this condition.

Valleau, Karraker and Johnson (54) pointed out in 1926 that the confusion in the literature of corn root rot diseases was largely due to the fact that investigators continued to emphasize a relationship between poor seed and seedling blight. Attention had been devoted to seed-borne pathogens neglecting the organisms actually associated with the diseased corn roots. They believed that plant pathologists had not given sufficient attention to an attempt to separate the various diseases concerned. The fact was emphasized that there was a root disease of corn distinct from seedling blight and the depressed growth resulting therefrom, and that the organisms previously considered as etiologic factors in corn root rot were not concerned. They pointed out (p. 455) that the cause of corn root rot was still given as *Gibberella saubinetti* in the *Plant Disease Reporter* in 1925 (53). These investigators, pioneering along such lines, concluded as the result of experiments that corn root rot, other than seedling blight known to be caused by seed-borne organisms, is a soil-borne disease caused by a fungus similar to the one causing cane root rot in Hawaii. The type of injury produced was stated to be (l.c. p. 475) remarkably similar to the injury to Lahaina cane pictured by Carpenter (5).

Branstetter (4), as a result of extensive field and laboratory studies in Missouri, arrived at the same conclusion as Valleau and his associates, i.e., that corn root rot is a soil-borne disease similar to cane root rot in Hawaii.

Johann, Holbert and Dickson (32), in 1926, reported an undetermined species of *Pythium* as the cause of seedling blight of corn in Illinois and Wisconsin. In a later publication (33), they summarized their observations in part as follows:

> *Pythium* injury to corn may be manifested as (1) a rot of the embryo, preventing germination, (2) as a seedling blight after emergence; or (3) as a root rot that tends to reduce the size, vigor and yield of the maturing plant. The causal organism has just been described by Drechsler (22) as *Pythium arrhenomanes* n. sp. . . .
>
> Experiments in which open pollinated and inbred corn was inoculated with *Pythium arrhenomanes*, at the time of planting, in soil temperature control tanks indicate that soil temperatures near 16° C. or lower, together with high soil moistures, are so favorable for infection that germination of corn kernels may be prevented or seedling blight produced. When inoculated corn is not killed in the seedling stage, the height and the dry weight of tops of the plants are reduced. The highest percentage reduction occurred at the lower temperatures. Evidences of differing degrees of resistance or susceptibility were manifest in different inbred strains of corn.

In the meantime, in 1927, Edgerton and Tims (24 p. 32) reported that a species of *Pythium* was consistently found in cane roots in different parts of the sugar cane belt. They remarked that *Pythium* was the only fungus found in Louisiana which consistently entered the stele portion of the root. Also, they remarked that the whole root was rotted, agreeing with our local observations.

Edgerton and associates (25, 27, 28) presented experimental data on the relation of soil moisture and temperature to the severity of cane root rot in Louisiana. They pointed out that root rot of sugar cane is more severe in poorly drained fields and in seasons of excessive rainfall and exceptionally low temperatures in January, February and March. Flor (27, p. 327), who used corn as an indicator in his experiments, reported some of his observations as follows:

> Although the growth rate of *Pythium* increases with the temperature up to 30° C., the effect of the fungus on growing plants is more severe at lower temperatures. Only young

terminal portions of the roots are subject to attack and it is possible that the cool weather holds the roots in a susceptible condition longer than warm weather.

The results obtained in the soil-moisture studies agree closely with conditions in the field. The effect of the fungus was severe only in soils with a water content greater than 50 per cent of the moisture-holding capacity. This emphasizes the importance of the best drainage possible, especially during winter and spring, when the cane grows very slowly. . . .

Pythium injury to germination and growth of corn decreased with rise in temperature. At 35° C., *Pythium* did not injure corn. At 30° C., there was an appreciable amount of injury, and, as the temperature was lowered, injury became more severe. *Pythium* injury to germination and growth of corn increased with the water content of the soil but was less severe in wet soils in warm than in cold weather.

Edgerton, Tims, and Mills (25) reported that certain species of *Pythium* which attack cane also attack a number of other members of the grass family including corn, sorghum, wheat and oats.

Rands (43) recognized the importance of *Pythium* sp. in root rot of cane in the southern United States. The most aggressive *Pythium* was considered to be representative of a type which was potentially the most important single factor in the cane root disease problem. This is the type of *P. arrhenomanes,* the cause of maize root rot in Wisconsin. The *arrhenomanes* group was thougth to include the Hawaiian *Pythium,* (see p. 287) cultures of which were included in his survey. As above mentioned, *P. arrhenomancs* was described by Drechsler in 1928 as a new species causing maize root rot.

Pythium Root Rot of Seedlings. The following excerpts are quoted from the writer's reports (17, 18) for the years 1931 and 1932.

In the (cane) seedling work steam sterilization of soil and flats insures the young plants a healthy start. Sterilized soil, however, furnishes an ideal environment for *Pythium* root disease and increases the susceptibility of plants grown therein in the same way as excessive applications of nitrogen. The apparently ubiquitous water and soil fungus, *Pythium,* soon infects the roots with disastrous results. The use of natural soil free of weed seeds or freed of such seeds by previously allowing them to germinate, seems to offer promise for use in seedling propagation. The elimination of weed seeds by germination before the soil is used for seedlings is mentioned in a recent paper by U. K. Das, referring to a practice in India. Rich soil and excessive moisture are the important factors in favoring *Pythium* root disease. Temperatures unfavorable for cane growth do not restrict the fungus but promote *Pythium* root collapse, at the same time retarding root replacement.

This disease had assumed considerable importance in seedling propagation during the expanded program of seedling production in the years 1928-29 and 1929-30. During the 1930-31 season the loss of seedlings was severe. Further sanitary measures were put into practice, this department cooperating with the geneticists in an attempt to eliminate the *Pythium* hazard. In the 1931-32 season this disease caused scarcely any loss of seedlings. It now appears that the disease can be completely controlled by a sanitation program, constant vigilance at all stages in the propagating house being essential to prevent seedling infection. When both the soil and the seedling flats are sterilized and care is observed to prevent infection from outside sources, no further difficulty is experienced. No treatment has proved successful in saving the seedlings once a flat has become infected.

In the last two seasons this disease has been under satisfactory control. Where excess moisture has been present, either applied in excess in the greenhouse or from rainfall where flats of young seedlings have been in the open at low temperature, root rot has been serious. Rich soil, excessive moisture and tempera-

tures low enough to check normal cane growth are favorable factors for excessive root destruction by *Pythium.*

Vanterpool and Ledingham (55), in a paper on the browning root rot of cereals, issued in 1930, considered that the disease under investigation was a *Pythium* root rot problem of cereals, especially of wheat, similar to the root rot complex of cane in Hawaii, Louisiana and elsewhere. Vanterpool and Truscott (56) reported in 1932 that under field conditions *Pythium* rarely reduced germination or injured the wheat seedlings but that it consistently caused a root rot which reduced the size and vigor of the growing plants. Two new forms of *Pythium* were concerned, *Pythium arrhenomanes* var. *canadensis* and *P. volutum.* The latter is reported (l.c. p. 78) as causing root rot of *Triticum aestivum* L., (wheat) and *Avena sativa* L., (oats) in Saskatchewan; also as an aggressive root parasite of *Hordeum sativum* L., (barley) *Secale cereale* L., (rye) and *Zea mays* L., (corn) when artificially inoculated. *Pythium arrhenomanes* var. *canadensis* causes root rot of *Triticum aestivum* L., in Saskatchewan. This variety is also an aggressive root parasite of *Avena sativa* L., *Hordeum sativum* L., *Secale cereale* L., and *Zea mays* L. Both fungi were considered to be closely related to the cane *Pythium* of Hawaii, but different therefrom. We quote from Vanterpool and Truscott as follows:

> Penetration of the roots of the cereal host by the two species of *Pythium* just described occurs readily through both the epidermal and root hair cells. Where the infection hypha comes in contact with the host cell wall, a small appressorium develops and a narrow infection tube pierces the cell wall, and, once inside, regains the normal diameter of the mycelium. The same phenomenon usually occurs when hyphae pass from cell to cell within the host. In so far as can be observed, the host offers no resistance to the invading parasite. The growing point of root or rootlet is most commonly attacked and consequently further growth in length is either retarded or stopped completely. Both fungi grow rapidly through the cortex in all directions and in the course of 24 hours or less have entered the stele of young roots....

In cooperative studies with the writer (14, p. 104), D. M. Weller found that *Pythium* was able to penetrate a cane root near the tip, apparently by pressure, and reach the center in 4 hours.

Flor (28, p. 32) studied the penetration of corn roots by *Pythium* and reported that infection near the root tip was unusually rapid. He stated that within 2 hours, the *Pythium* hyphae had entered the epidermal cells; in 4 hours, the first three or four tiers of cells had been penetrated; and in 6 hours, the fungus had nearly reached the central cylinder. Within 24 hours, the root tip had been completely invaded by the fungus, and the cells had collapsed. Penetration of cortex tissues that were 16 hours old when inoculated was nearly as rapid as through the root tip cells. The uninjured cortex of roots 48 hours old, when inoculated, was not as readily entered. Flor concluded that most of the infection and rotting occurs in young tissues, which is in harmony with our observations.

A new and serious disease of maize, said to be different from root rot caused by *Pythium arrhenomanes* in the United States is reported by Curzi (21) in Italy. The cause was considered to be a *Pythium* sp. of the *P. gracile* group. This disease was said to have caused a loss of 80 per cent of the crop.

The occurrence of *Pythium* root rot of maize and cane in the Philippine Is-

lands is recorded by Roldan (45). Concerning root rot of rice in the Netherlands East Indies, Leefmans (34) reported as follows:

Root rot of rice, though still widespread, appears to have generally declined in severity, partly as a result of the application to the soil of double superphosphate. Infection by *Pythium* was again observed on rice crops cultivated under dry conditions at Bodjonegoro (Rembang).

Sideris and Paxton (49) supported the writer's (5, 6) opinion that pythiaceous fungi were responsible for considerable root damage of pineapples and were, in part at least, responsible for pineapple "wilt" disease. This disease in its several forms is common in the pineapple fields of Hawaii. The foliage of the plants turns to various shades of yellow, red or brown, shrivels slowly and the plants often die. Scant root systems are the rule on such plants. Sideris and Paxton state (l.c. p. 496) that, "root rot caused by pythiaceous organisms is probably one of the important causes for the development of the disease known as wilt."

Sideris (48) made a taxonomic study of the pythiaceous fungi associated with pineapple root rot. It may be noted that a subdivision of the family *Pythiaceae* into the genera *Nematosporangium* and *Pythium* has been adopted by some authorities, while others have not recognized *Nematosporangium* as a genus and have supported a division of the family into the two genera, *Pythium* and *Phytophthora*. Sideris advocates the recognition of *Nematosporangium*. He described eight new species and one new variety of this genus.

Vanterpool and Truscott (56, p. 71) reported difficulty in identifying their *Pythium* types with those of several closely related forms described by Sideris, by the descriptions alone. Their comment on these species and the difficulties involved in taxonomic studies of the *Pythiaceae* is quoted as follows:

The identification of many of these species which are morphologically very similar is unfortunately based on cultural differences on a variety of plant media some of which (and among them the most important, papaya agar) are unobtainable in temperate climates. Some justification may be found for this procedure, but it unquestionably makes it more and more difficult for workers who have obtained one or more of these morphologically similar species to know definitely what forms they are working with. The accurate determination of the identity of a species would entail an enormous amount of comparative culture work and would have to be undertaken by one or two authorities on the group. The most common Saskatchewan wheat *Pythium* is morphologically very similar to several species described by Sideris but whether it is identical with any one of them cannot definitely be determined from the descriptions alone.

We have not made a critical study of the family *Pythiaceae* and do not propose to enter the discussion as to what constitutes a species. It is obvious that to distinguish between such closely related forms a meticulous technique is necessary. Whenever it is sufficiently important to accurately identify a certain form to justify the work required, it is desirable that the technique be workable by all investigators who may find it expedient to employ it.

In the first description of the *Pythium* sp. associated with root rot in Hawaii (5, 7), it seemed to the writer that in the current state of knowledge, it was far better to state that this fungus with its prosporangia of the *Nematosporangium* type was morphologically like certain described forms than to claim new species on the basis of small differences. Several investigators have expressed opinions

as to the identity of the cane fungus which we have been referring to as *Pythium aphanidermatum* (Edson) Fitz. In Bulletin III, part 1, Botanical Series, H.S.P.A., the fungus was stated to be morphologically identical with *P. Butleri* Subramaniam and *Rheosporangium aphanidermatus* Edson. The name *Pythium Butleri* Subramaniam was given preference by the writer. Fitzpatrick (26) presented reasons why this fungus should be more appropriately referred to as either *Pythium* or *Nematosporangium aphanidermatum* (Edson). Drechsler (22) stated that the cane *Pythium* as described and figured by Carpenter had a slightly different type of antheridium than *P. aphanidermatum* and, one which more resembled that of his new species *(P. arrhenomanes)*.

Rands (43) compared cultures of the Hawaiian *Pythium* sp. from root rot of cane with the isolations he was studying. He stated that the most parasitic group had been tentatively assigned by Drechsler to *P. arrhenomanes,* the causal fungus of maize root rot in Wisconsin. These fungi were considered potentially the most important single factor in the root disease problem of cane. The cane *Pythium* from Hawaii was considered closely related to this group.

Matthews (38) agreed with Fitzpatrick and Carpenter that *Pythium Butleri* is the same as *P. aphanidermatum.* The opinion was expressed that the Hawaiian *Pythium* is not *P. aphanidermatum* and it was classified as identical with *P. graminicolum,* described by Subramaniam (51) in 1928. The latter isolated a species of *Pythium* from root rot of wheat. We quote a portion of his description as follows:

> It does not agree with any of the described species of the sub-genus *Aphragmium.* It agrees with the description and drawings of the *Pythium* on sugar cane studied by Carpenter (7) in Hawaii.
>
> . . . The measurements of the *Pythium* (oogonia and oospores) on cane are slightly bigger than those of the *Pythium* on wheat but they are not sufficiently great, I think, to separate the two fungi.
>
> A new name is proposed for the fungus on wheat, "*Pythium graminicolum* n. sp."

We are forced to admit that in this case it would have been less confusing to create a new species for the Hawaiian cane *Pythium* in the first place, however small the difference from described species.

A paper by Rands and Dopp (44) entitled, "Variability in *Pythium arrhenomanes* in relation to root rot of sugarcane and corn" was received (September 5, 1934) after the manuscript of this paper had been submitted for publication. In order to clarify the synonymy of the *Pythium* sp. with which we have been chiefly concerned, we quote from Rands and Dopp as follows:

> This paper presents the results of laboratory and greenhouse studies on strain variability of the principal sugarcane root-rot fungus, *Pythium arrhenomanes* Drechsler, in Louisiana and Florida. Additional cultures from corn root rot in the North Central States, the cereal root-browning fungus from Canada, and sugarcane strains from Hawaii and Mauritius were included in the laboratory comparisons.
>
> Despite wide differences in size of oogonia, number of antheridia, rate of growth in artificial culture, and response to temperature, and despite variation in hydrogen ion concentration and in virulence among the local forms on sugarcane and corn, certain constant and distinctive characteristics of the sexual organs unquestionably classify all the 70 isolates tested as *Pythium arrhenomanes.* Nine of the recently described *Nematosporangium* species of Sideris mainly from pineapple in Hawaii, are also included under the species.

Rands and Dopp (p. 218) are quoted again as follows:

That all the isolates herein studied belong to this species is obvious from their morphologic similarity alone. The typical crook-necked antheridia and the remote connection between male and female organs are believed to be more characteristic of the species as a whole than a large number of antheridia, emphasized by Drechsler. Unfortunately, all the relatively few fruiting cultures studied by Drechsler showed large numbers of antheridia but such are not characteristic of many representatives of the species. A considerable proportion of the isolates included in these studies had typically but 4 to 10 visible antheridia instead of the 15 to 20 mentioned in the species description. . . .

Henceforth, as a result of the comparative studies of cane and corn root-rot fungi reported by Rands and Dopp, the parasitic fungus associated with growth failure of cane in Hawaii referred to first as *Pythium Butleri* Subramaniam and more recently as *P. aphanidermatum* (Edson) Fitzpatrick, will be considered synonymous with *P. arrhenomanes* Drechsler. According to Subramaniam (51) cited above, his *Pythium graminicolum* is identical with the *Pythium* in Hawaii, a decision in which Matthews (38, pp. 51-59) concurs. The species description of *P. graminicolum* apparently takes precedence over that of *P. arrhenomanes* by Drechsler since Subramaniam's paper published the same year as Drechsler's—in what month we do not know—bears the note "Received for publication the 21st February, 1928." A footnote states that the paper was read at the fifteenth meeting of the Indian Science Congress, Calcutta, 1928. This meeting was held January 2 to 7, 1928. The Proceedings of this Congress, published in 1928 without record of the month, contains an abstract of Subramaniam's paper (page 232) which states that the name *P. graminicolum* is proposed for the *Pythium* found on wheat and sugar cane. Drechsler's description of *P. arrhenomanes* was published in the October number of *Phytopathology*, 1928. References made to the Hawaii cane *Pythium* throughout this paper as *P. graminicolum*, before receiving the paper of Rands and Dopp, have therefore been left unrevised, in view of the apparent priority of that name.

The foregoing review of the literature illustrates the increasing attention given by phytopathologists in various parts of the world to pythiaceous fungi as active causes of obscure plant diseases of the "root rot" and "growth failure" types. The citations furnish considerable correlative information in support of experimental evidence presented later to reveal the determining relation of various forms of abnormal nutrition of the host plant to susceptibility.

Improvement of Cane Growth in Steamed or Fumigated Soils

The improved growth of plants in steamed soil in comparison with non-steamed soil has long been a subject of comment in agricultural literature. A similar improved growth accompanied by similar changes in root habit also occurs in chemically fumigated soil. Studies of this phenomenon, collaterally of interest in the general root rot problem, have received attention in cooperation with the Chemistry, Entomology and Agricultural Departments. The reader is referred to Webster's (59) paper for a resumé of the literature on plant response to sterilized soils. It may be said that some soils are reported to show a growth response when partially sterilized but growth depression when completely sterilized. In our experience with cane, Hawaiian soils, with some exceptions, respond to complete

sterilization, by which we mean steaming in bags 3 hours or more at 25 pounds pressure.

Maxwell O. Johnson of the California Packing Company had called attention to the remarkable improvement in growth of pineapples on Hawaiian soils treated with chloropicrin. Subsequent pot studies by William Hartung and C. L. Crutchfield of the Pacific Guano and Fertilizer Company, showed similar growth improvement of tomato plants following chloropicrin treatment of soil where pineapples had failed. Cooke (20) observed a similar response of growth failure soils with Sudan grass as an indicator plant. These observations, as Cooke has outlined in more detail, inspired the effort to learn how the improvement of crop growth was effected. Cooke stated (p. 171) that a respiration test showed that more carbon dioxide was given off by untreated soil than by chloropicrin-treated soil. Coincidentally, as a matter of interest, it may be pointed out that just such an observation by Russell and Buddin (46) regarding oxygen absorption by soils inspired their classic investigation of the interesting phenomenon of improved growth of plants in partially sterilized soil. A short review of their fundamental work on the subject is necessary as an introduction to this phase of our studies.

Russell and Buddin stated that much of the work recorded in their paper entitled, "The Action of Antiseptics in Increasing the Growth of Crops in Soil" was the outcome of a mistake committed by a youthful laboratory attendant. The absorption of oxygen by various chemical substances was under investigation. Soils were finally included and it was observed that fertile soils absorbed oxygen more rapidly than non-fertile soils of the same character. The rate of oxygen absorption was useful as an indication of productiveness. Since the oxygen absorption was reduced in sterilized soil, it was concluded that the process was largely due to microorganisms. Through an annoying mistake sterilization was only carried out at 100° C. and not at 130° C. The partially sterilized soil was used in an experiment with remarkable results. This soil absorbed oxygen much more rapidly than the unsteamed soil. Subsequently, partial sterilization with volatile antiseptics gave similar results. Pot experiments showed, as anticipated, that the partially sterilized soils were more productive than untreated soils. This fact had already been noticed by a vine grower in Alsace, who treated his vineyard soil with carbon disulphide to control phylloxera, and noticed a marked increase in crop. This last observation inspired an investigation by Hiltner and Störmer (29) in Germany, who associated bacteria with the beneficial effects of sterilization.

Hutchinson, according to Russell and Buddin (46, p. 1137), definitely established the following propositions:

1. **Partial sterilisation causes first a fall and then a large rise in the numbers of bacteria in the soil.**
2. **Simultaneously there is a considerable increase in the rate of production of ammonia from the complex nitrogenous compounds of the soil.**
3. **The increased productiveness of partially sterilised soil is due, at any rate in part, to this increased productiveness of ammonia.**
4. **The increase in bacterial numbers is the result of improvement in the soil as a medium for bacterial growth and not an improvement in the bacterial flora. Indeed, when the original bacterial flora is introduced into partially sterilised soil the numbers rise even higher than when the new flora is left to itself.**

5. The improvement in the soil is permanent.

6. But if some of the untreated soil is introduced into partially sterilised soil, the bacterial numbers after an initial rise begin to fall and the fall is out of all proportion to the amount of added soil.

These and other experiments show that ordinary soil contains a factor which keeps down the bacterial population and prevents it from attaining maximum numbers. The factor is not bacterial; it appears, however, to be living, and to consist in organisms larger than bacteria, more readily killed, and more slow in multiplication under soil conditions. Search for organisms fulfilling this description was made, and revealed the presence of numerous protozoa, the existence of which had hardly been suspected before.

When this detrimental factor is put out of action by gentle heat or by antiseptics, the bacterial numbers increase, more plant food is formed, and the productiveness of the soil is raised.

Webster (59) reported observations in two pot experiments. One experiment was with nine varieties of cane in steam-sterilized soil, formaldehyde-treated soil, and untreated soil. In every case the plants in the sterilized and treated soil responded with superior top and root growth. A sample root system representative of each variety in each treatment was examined by R. H. Van Zwaluwenburg and the writer. Their observations are quoted from Webster's paper (p. 340) as follows:

Herewith is submitted a report on an examination of the roots of 27 samples of cane from an experiment conducted by J. N. P. Webster. These 27 samples consisted of 9 varieties in three series as follows:

A—Check Makiki soil
B—Steam-sterilized Makiki soil
C—Formaldehyde-treated Makiki soil

The varieties of cane were as follows:

D 1135	Lahaina
P.O.J. 2878	Badila
Yellow Caledonia	Natal Uba
P.O.J. 36	Striped Tip
H 109	

The top growth of the canes in the treated soils was in general so superior to that of the plants in the natural Makiki soil that it seemed worth while to know whether or not the observed improvement was due to repression of parasitic organisms, and with that in mind the roots were examined.

The root systems of all plants were carefully washed. The following general observations were made:

1. The root growth of the plants in the steam-sterilized soil was in most cases superior to, and in all cases at least equal to, that obtained in formaldehyde-treated soil.

2. The root systems in the treated soils were in all cases far superior to those in the natural soil. By superior is meant of greater bulk and with a very conspicuous increase of fine rootlets, particularly in the upper 6 inches of soil. (A single exception was the Natal Uba in soil treated with formaldehyde; here depression resulted.)

3. The roots in the treated soils were conspicuously lighter in color than those in the checks.

4. The roots of all three series showed conspicuous injury due to contact with the container.

5. *Heterodera radicicola* and *Tylenchus similis* were identified in all pots of the check series. In every case, however, damage by these nematodes was so slight that it was impossible for us to believe that the marked reduction in root and top growth shown throughout

the check series was due to these factors. No evidence of rootlets having been destroyed by nematodes was seen in the check series. In only two cases of treated pots, one steam sterilized, the other formaldehyde treated, were traces of Heterodera found. No Tylenchus was found in roots of treated pots.

6. No evidence of *Pythium* root rot was observed in the series in treated soils. In the natural soil an occasional softened root was found, but in no case was the fungus *Pythium* definitely observed. Such roots as were softened appeared to have succumbed as a result of stagnation in the water in depressions at the bottom of the pots.

The striking difference between the roots of treated and check pots was the comparative lack of fine rootlets in the latter. There was no evidence that this lack of fine roots was due to the destruction by parasitic organisms of rootlets already formed. On the contrary such rootlets apparently had never been developed in corresponding abundance in the check plants.

It is our presumption, therefore, that the essential factors controlling the abundant production of secondary rootlets are physical and nutritional in nature. When ample nutrients in an improved physical environment were available, a close mat of fine roots developed.

We suggest that if this project is to be followed, a series of soils be included wherein a superabundance of nutrients is present in both sterilized and unsterilized units, to eliminate the possible lack of nutrient factors. Fine screened soil might be used to make the physical condition of steamed and check soil more nearly comparable. Inoculation of a series of steamed soils by the introduction of small amounts of natural soil might throw additional light on the biological-nutritional phases of the problem.

The statement is made by Russell (l.c. p. 1141) that only soils low in nitrogen respond to sterilization and that the same effect secured by sterilization could be had economically by applications of fertilizer. It should be noted that the soil used by Webster was from Makiki field plots. This soil, naturally low in nitrogen, is one in which *Pythium* root rot has never been considered a crop hazard, even for Lahaina cane. Elimination of *Pythium* by the treatments apparently was not an important factor in the improved growth.

Webster's first experiment led to a second one with the idea of duplicating the response to steam sterilization by fertilizing with phosphate, with complete fertilizing mixture, and with chloropicrin treatment. The experiment with the variety D 1135 comprised sterilized and unsterilized Makiki soil with the treatments indicated in Table I, quoted with comment from Webster (Table II, l.c. p. 348). The table also shows the dry weights of the tops and roots.

TABLE I

Treatments	Sterilized Soil		Unsterilized Soil	
	Tops	Roots	Tops	Roots
Check	360.1	140.2	115.6	69.9
Unsterilized soil added (2 lbs.)	385.6	134.2	...	...
1000 lbs. P_2O_5	326.3	130.5	89.6	60.8
1500 lbs. P_2O_5	291.2	132.9	95.8	58.1
100 lbs. N, 500 lbs. P_2O_5, 500 lbs. K_2O	419.6	111.5	160.5	89.8
Pythium	405.1	111.0	86.4	49.1
Chloropicrin 75 lbs. per acre	380.1	145.0	229.6	102.3

A first glance at the above table shows the remarkable gain of the top and root weight of the sterilized soil series over the unsterilized series.

The greater weight of tops and roots of the sterilized soils is in accord with that found in Experiment 1.

The response to chloropicrin in the unsterilized soil is considerable and is probably due to its sterilizing effect upon the soil.

The following comments, based on Webster's data, may be entertained:

1. *Nitrogen:* The results with complete fertilizer tend to support Russell's statement that the response to sterilization may be realized by fertilization. The failure of the plants, grown without shelter from rains, to respond in the same degree might be interpreted as due to leaching of the nitrogen from the fertilized pots. Nitrogen at the rate of 100 pounds per acre mixed with the soil before planting might not be equivalent in growth value to ammonia liberated gradually in the unfertilized soil by accelerated biological processes following sterilization. The plants in soil fertilized with the complete mixture and sterilized were superior in top growth and inferior in root growth to the plants in sterilized unfertilized soil.

A considerable growth response to chloropicrin in unsteamed soil was evident. This response indicates that heat and the immediate and direct changes such as might result from steam sterilization are not the vital factors. No significant response was secured by chloropicrin treatment of steamed soil, indicating not only that chloropicrin did nothing that steaming had not already done, but also that chloropicrin in itself added no nutrients directly or indirectly by chemical action.

2. *Phosphate:* It appears fair to assume that phosphate applications and the *Pythium* inoculations, in this soil with D 1135, were without appreciable effects. The lack of response to phosphates indicates that the soil was sufficiently supplied with this element to balance the nitrogen and potash present. Both sterilized and unsterilized soil benefited from the nitrogen and/or potash in the complete fertilizer.

3. *Addition of Unsterilized Soil to Sterilized Soil:* The addition of two pounds of unsterilized soil to the sterilized units was without apparent harmful effect, indicating that root parasitic flora or fauna were not factors the suppression of which by sterilization permitted "normal" growth.

Various collaborators in this project have commented upon the superior root systems of sugar cane grown in steamed or chemically fumigated soil. The roots are white, as in water cultures, and in the upper soil layer form a dense mat of fine, fibrous rootlets. Healthy roots in similar soil, unsterilized, are rarely, if ever, as light in color and have not been observed to be accompanied by such a mass of fine rootlets. Russell and Petherbridge (47) mention just such a remarkable development of fibrous roots by plants grown in soils heated to 100° C., unlike anything obtained in untreated soils.

It was of interest to Mr. Agee and our co-workers to learn if such extensive root systems could be regarded as normal, and if the root systems of crop cane in general were curtailed by unknown root-destroying parasites. As noted above, in the comment of Van Zwaluwenburg and the writer on Webster's experiment, examination failed to produce any evidence that parasites—either microfauna or microflora—were significantly concerned. However, the possibility that such factors are active was not overlooked as a result of this lack of evidence. In the light of our observations, it appeared more probable that the growth response to sterilization was due to a greater availability of nutrients, presumed to result from changes in the soil biology, a predominating viewpoint in the literature.

It is obvious that there are two phases to the question of enhanced growth in sterilized soils, as follows: (1) The elimination of parasites such as *Pythium* sp. in soils where root parasites are significant factors. (2) The stimulated growth in soil where the suppression of root parasites apparently is in no way concerned. The experiments recorded below, in which *Pythium* is not considered to have been a factor, tend to support the view that the stimulated growth following sterilization by steam or chemical fumigation is due to enhanced nutrition, presumably from ammonia released by biologic activity.

Mixed Sterilized and Unsterilized Soil: It was thought that the growth of cane in a series of steamed soils mixed with gradually increasing increments of unsteamed soil might serve as a key experiment. If undetected root parasites were preventing normal growth in the unsterilized soil, then a small addition of unsterilized soil to the sterilized soil should introduce such parasites and serve to produce a growth depression corresponding to that in the unsterilized soil alone. On the other hand, if the improved growth in sterile soils were to be attributed to a greater solubility of nutrients, biological release of ammonia, etc., the increase in growth would be expected to be somewhat progressive with an increasing proportion of sterilized soil.

As another phase of this experiment, pots were filled with sterilized soil at one side and unsterilized soil on the other (a board partition dividing the interior until the soils were in place). In another series of pots in the experiment it was sought to demonstrate that the improved growth and mass of fine rootless characteristic of sterile soil were a response to nutrients and that the effect could be duplicated with fertilizers. These soil experiments were installed July 28, 1931.

The soil for the experiment consisting of thirty units was collected from the same locality at Makiki as that used by Webster in his experiments mentioned above. The soil was screened and thoroughly mixed. One-half was steamed 3 hours at 25 pounds pressure. H 109 cuttings from Field 15 at Makiki were planted in the various units, the treatments of which are shown in Table II.

TABLE II

Pot Numbers	Treatment
1 - 2	Unsterilized soil.
3 - 4	Sterilized soil.
5 - 8	Sterilized soil in one side of pot; untreated soil in other side.* Two seed pieces planted across the contact plane of the two soils.
9 - 10	Sterilized soil fertilized with nitrogen, phosphate and potash.
11 - 12	Unsterilized soil fertilized with nitrogen, phosphate and potash.
13 - 14	Sterilized soil fertilized with ammonia.
Root boxes, numbers	
17 - 18	Unsterilized soil.
19 - 20	" " 9/10†, Sterilized soil 1/10
21 - 22	" " 7/10, " " 3/10
23 - 24	" " 5/10, " " 5/10
25 - 26	" " 2/10, " " 8/10
27 - 28	" " 1/10, " " 9/10
29 - 30	Sterilized soil.

*The soils were separated by a board partition until the pots were filled; the board was then removed.

†Parts by volume, mixed and placed in boxes.

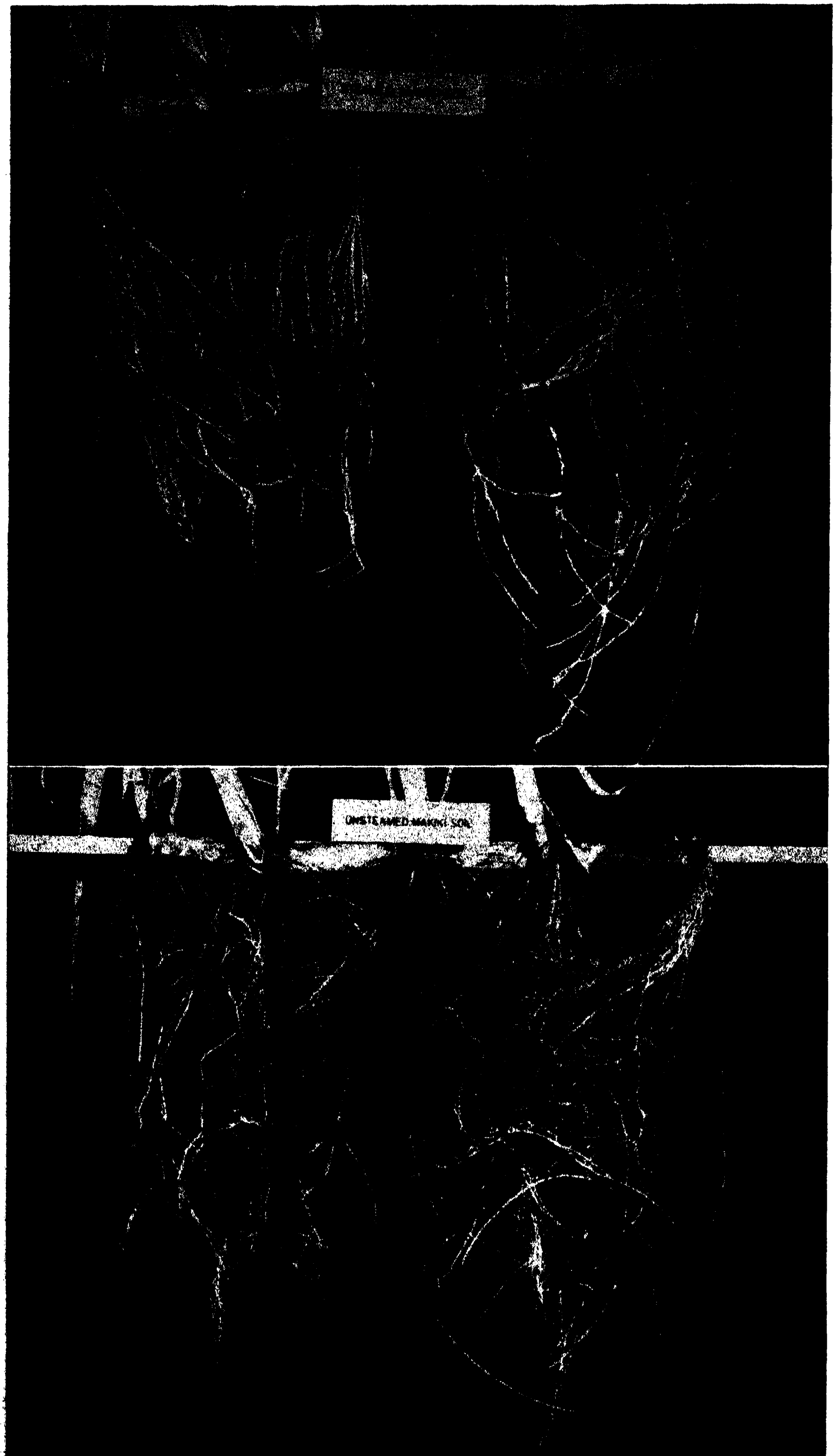

Fig. 1. Root systems of H 109; above, in steamed Makiki soil; below, in natural Makiki soil.

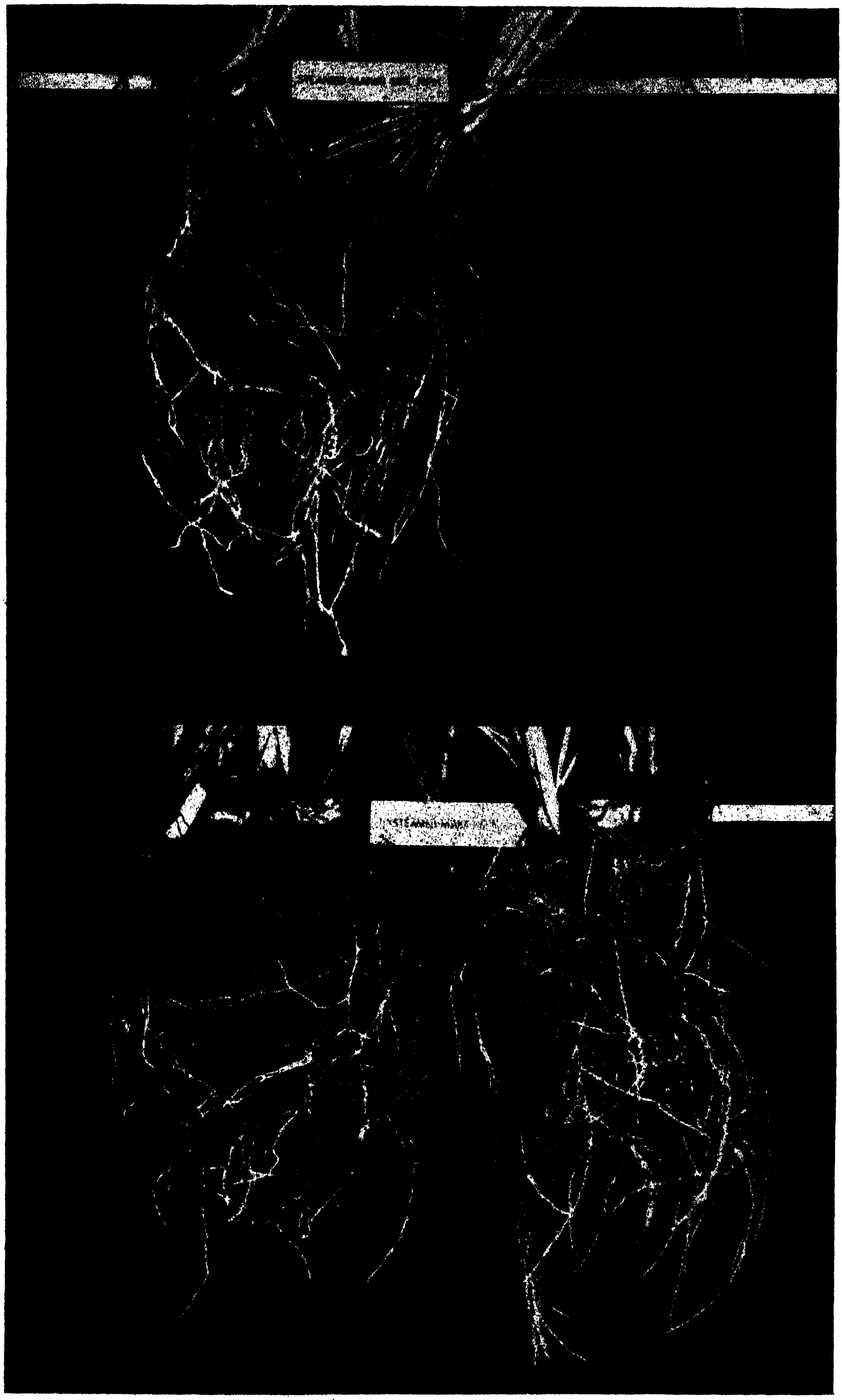

Fig. 2. Root systems of H 109; above, steamed soil fertilized with nitrogen, phosphate and potash; below, unsteamed soil, similarly fertilized. Compare with Fig. 1.

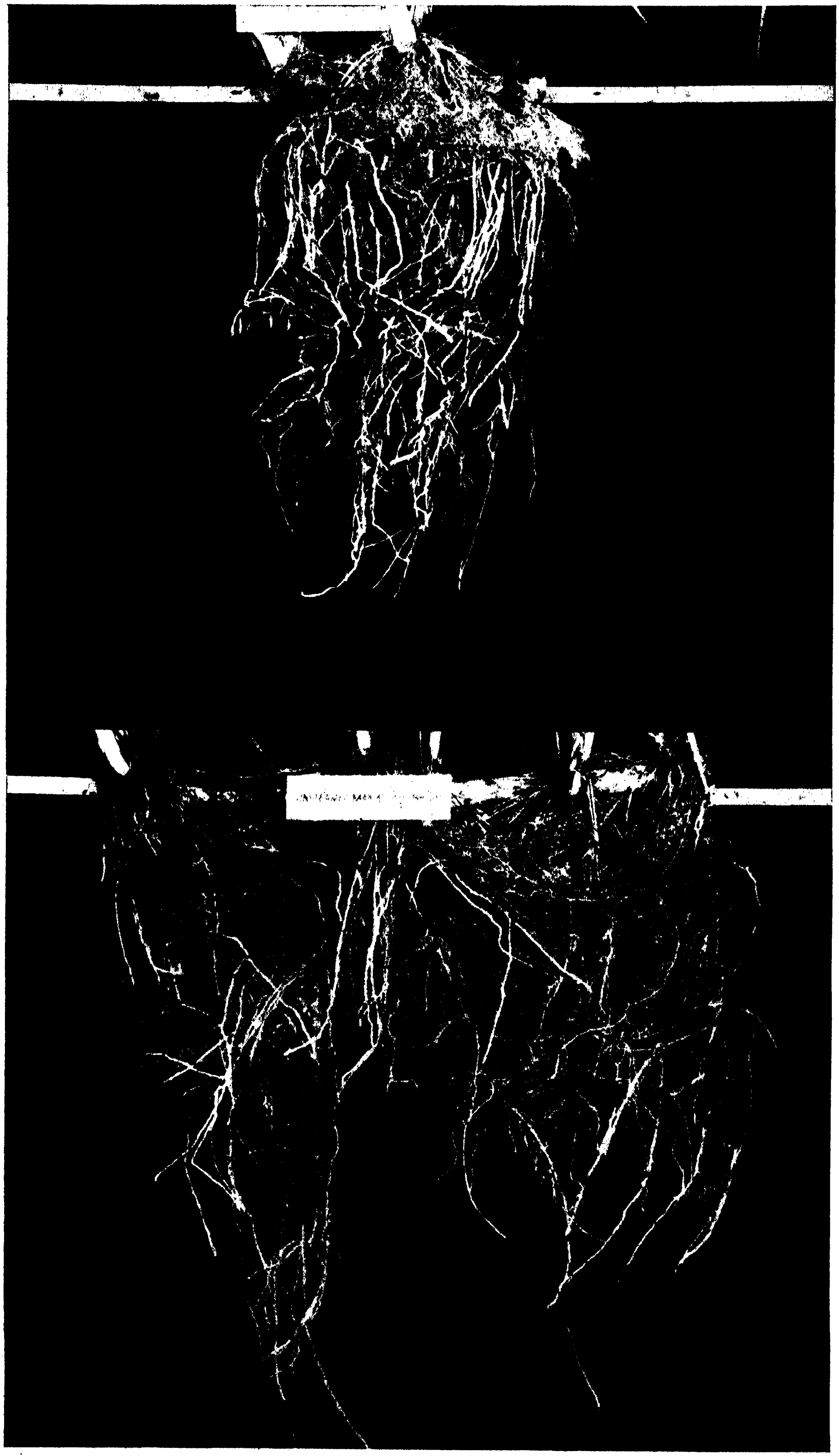

Fig. 3. Root systems of H 109; above, in steamed soil fertilized with ammonia; below, natural soil fertilized with ammonia. Compare with Fig. 1.

The root systems were exposed after 2½ months by washing out the soil. Mr. Van Zwaluwenburg joined in the inspection. Observations and deductions from the experiment may be summarized as follows:

Unsteamed Soil: The plants in unsteamed and unfertilized soil grew comparatively slowly and at the conclusion of the experiment were small, with pale green leaves. The root systems were comparatively small, with few fine rootlets. The roots appeared healthy. (Fig. 1.)

Steamed Soil: The plants in steamed soil were superior in size and color to those in the unsteamed soil. They were about as large as any plants in the fertilized soils but the leaves were not as deep green in color. The root systems were much superior to those in the unsteamed control soil, with conspicuously large white main roots and masses of fine rootlets. (Fig. 1.)

Sterilized and Unsterilized Soil, Fertilized: Some of these pots received a total of 25 grams of complete fertilizer (B 9 = 11 per cent or 2.75 grams nitrogen, 6 per cent or 1.5 grams phosphoric acid [P_2O_5], 6 per cent or 1.5 grams potash [K_2O]). Those fertilized with ammonia received five applications of one liter of water containing ammonia equivalent to a total application of about 7.5 grams of nitrogen per pot. As noted above, the foliage of the plants in fertilized, unsterilized soil was a darker green than that of the plants in sterilized soil, unfertilized, and the plants appeared somewhat more vigorous. The root systems were comparable with those in steamed soil and of about the same habit, but possibly had somewhat less fine rootlets. (Figs. 2 and 3.)

The characteristic mass of fine rootlets commonly observed in sterilized soils corresponding to those seen where cane is grown in water for a long time without added nutrients (p. 332 and Fig. 26) appears to be the result of growth in dilute solutions of nutrients. In sterilized soil this might be attributed to the gradual liberation of ammonia in very small amounts throughout the soil mass as a result of the entrance and activity of biological factors. Russell and Petherbridge (47, p. 257) stated that under the conditions of their experiment dilute solutions of ammonia enhanced the germination of seed.

Where ammonia or nitrate are added as nutrients to soils the root system takes on the character of larger roots, comparatively few in number or sparsely branched. In dilute nutrient solution or in water, many long, hair-like rootlets form apparently as a result of the low concentration of nutrients. Just as the aerial parts of plants become attenuated in weak light, so the roots appear to draw out in hair-like form as a result of a deficiency of essential elements. (Fig. 26.) The opposite happens as well-nourished cane stools increase in size, a fact reported by Venkatraman and Thomas (57). The roots from the cyme rings or root bands of the planted cuttings start out small, the tips increasing somewhat in size with increasing length. The primary roots from the bases of the first shoots, while larger than the roots from the cuttings, are relatively small in the young cane stool. As the stool increases in size and vigor of growth in rich soil, the primaries from the successive suckers are of increasing size and the distal absorbing portions and tips may increase further in size as they extend themselves in the rich soil, until they may be nearly as large as a pencil.

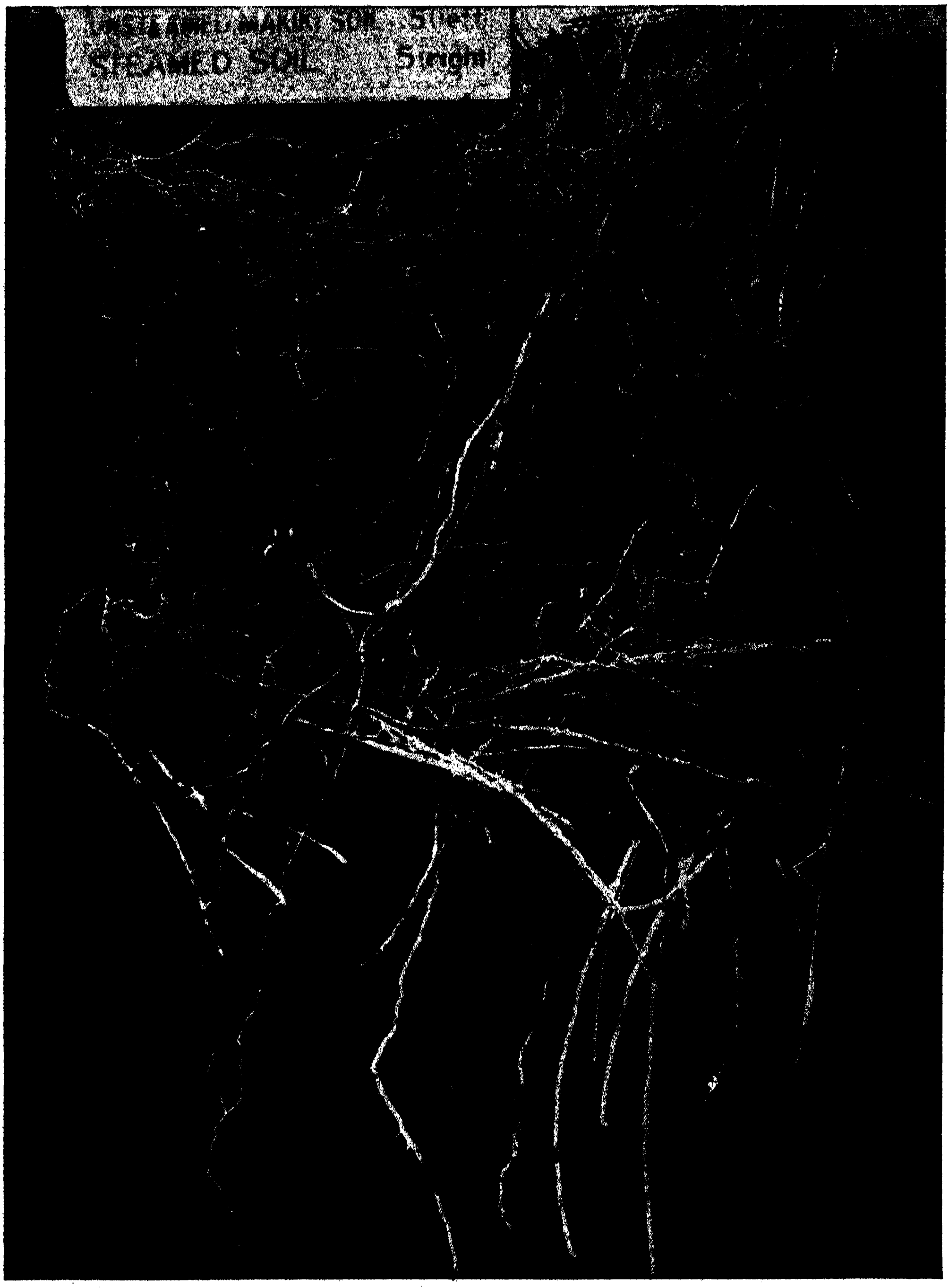

Fig. 4. Root system of H 109. Left half of roots developed in natural Makiki soil; right half in steamed Makiki soil. Note the dense mass at right with matted hair-like rootlets.

It seemed obvious that the improved top growth as a result of steaming the soil had been duplicated in the unsteamed soil by fertilization. Differences of root habit were of degree rather than of type. In other experiments it was significant that noticeable improvement of growth did not occur in fertilized soil as a sequel to steaming. In other words, as Russell has remarked, if the soil is amply supplied with nutrients, particularly nitrogen, steaming it will not serve to materially increase plant growth.

In the sterilized soils mixed with increasing amounts of unsterilized soil, there was a marked decrease of growth where 50 per cent or more of unsterilized soil was present. Less than this amount had no appreciable effect. The tops and root systems indicated that there was ample food present or gradually being elaborated in the sterilized soil to tolerate a 50-50 dilution with unsterilized and potentially less fertile soil, but that a greater dilution reduced the available or potentially available nutrients to the approximate condition of the unsterilized soil.

This behavior is incompatible with the root parasite theory; i.e., that these parasites are responsible for the lesser growth in unsterilized soil. We would expect small amounts of unsterilized soil to infect the sterilized soil and be as harmful as large amounts. If protozoa, which destroy the beneficial bacteria, were introduced with the unsterilized soil, we would expect a similar result but somewhat delayed since these organisms would be limited at first by bacteria for food.

The theory that growth increase is due to the elimination of root parasites is again negatived by the root habit of cane planted across the dividing plane of sterilized and unsterilized soil in the same containers. In these pots, a thin board cut to fit the contour of the pot was placed vertically, dividing it into halves. Steamed soil and unsteamed soil were poured simultaneously into the respective halves of the pot. The position of the dividing plane was oriented and marked on the outside of the pot before the board was removed. Two three-eye cuttings of sugar cane were planted across the dividing plane of the two soils in each pot.

When the soil was washed from the roots, it was noticeable that the roots in the unsterilized soil were comparatively lacking in fine rootlets in contrast to those present in the sterilized soil. (Fig. 4.) It appeared that the roots in the sterilized portion had developed much more extensively as a result of some factors not present in the untreated soil. If we assume harmful factors such as parasites to be present in the unsteamed soils, it is difficult to explain their failure to migrate into the sterilized soil. If we assume the presence of protozoa, which destroy beneficial bacteria (ammonifiers), it is equally difficult to understand why there was no indication of their migration. There was no physical barrier, the two soils being in intimate contact.

Turning again to the hypothesis that growth improvement in sterilized soil is due to an increase of available nutrient, the phenomenon may consist of an initial increase due to the sterilization agents and/or a progressive increase due to changed biological balance, elimination of protozoa and the resulting ascendancy of a population of beneficial organisms, e. g., ammonifying and nitrifying bacteria. The dominant theory advanced by investigators seems to be that growth response in sterilized soil is due to increases of ammonia and an increased solubility of organic matter and that, in addition, with a reduced competition for the nutrients

due to a changed biological activity, the plant obtains a larger proportion. When the sterilization is brought about by steam, we would expect some increased solubility of nutrients and other profound chemical and physical changes as a direct result of heat. Since fumigation with such diverse chemical compounds as chloropicrin, carbon bisulphide, toluene or formaldehyde, for examples, produces a similar improvement, an initial increased solubility of nutrients seems illogical. Considering this phase of the problem, a progressive increase in availability of nutrients (liberation of ammonia) as a result of biological activity seems more logical (see p. 290 *re* suppression of Protozoa).

At first glance, it might appear that the biological theory of increased availability of one or more nutrients as the result of a predominance of such beneficial organisms as Nitrobacter, Nitrosomonas (ammonifying and nitrifying bacteria, etc.) offers a plausible explanation. However, considerations difficult to harmonize with this viewpoint are not lacking.

For example, in the above experiment, where steamed and unsteamed soil were mixed, the biological balance might be assumed to be changed favorably in the former by the treatment and in the unsteamed soil would be presumed to remain unchanged. Now, if these soils be mixed thoroughly in the proportion of equal parts, we would expect the biological factors of each soil to be modified by the other. The mixture, unless initially made richer as a direct result of the steaming of half of its content, should have as the result of changes in biological balance, half of the "stimulating" effect of steamed soil and half of the "depressing" effect of unsteamed soil. Yet this half-and-half mixture grew plants and root systems comparable with those in sterilized soil alone.

It is difficult to imagine a visible soil improvement, as evidenced by enhanced plant growth over a two-month period, to be the result of a changed biological balance when all factors for a readjustment of the balance to the original condition may be presumed to be present from the time the soils were mixed. On the contrary, if the effect is considered to be due to an immediate increase of available nutrients as a result of steaming *per se,* how shall we interpret the improved growth obtained either with chloropicrin or formaldehyde?

Therefore, it was important to know whether the improvement factor which enhances plant growth is present *in toto* immediately after steaming a soil or if it is gradually evolved and as gradually becomes available as a plant stimulant. Quoting from Carpenter (18, p. 31):

Since ammonia was indicated in the above studies as the chief source of the increased growth, an experiment was conducted in cooperation with F. Ray Van Brocklin, associate chemist, to determine the changes in amount and forms of nitrogen occurring in soil following steam sterilization. Sufficient Makiki soil was screened to fill four crocks. Two crocks of soil were steamed at 15 pounds pressure, for three hours. One crock of steamed soil and one of natural soil were then analyzed by Mr. Van Brocklin to obtain information on the forms of nitrogen, and indications of any change due to steaming *per se.* Duplicate crocks of steamed and unsteamed soil were incubated from July 12 to August 29, 1932, in a moist condition, for the purpose of determining the changes in forms and amounts of nitrogen, incident to biological action. The second series of soil was then analyzed by Mr. Van Brocklin.

The analytical data obtained by Mr. Van Brocklin are summarized by him as follows:

	Analysis immediately after sterilization	Analysis after 6 weeks' incubation
	Total nitrogen (dry basis)	
Natural	1220 p.p.m.	1270 p.p.m.
Sterilized	1230 p.p.m.	1280 p.p.m.
	Ammonia nitrogen (dry basis)	
Natural	16.4 p.p.m.	5.9 p.p.m.
Sterilized	27.6 p.p.m.	40.9 p.p.m.
	Nitrate nitrogen (dry basis)	
Natural	17.3 p.p.m.	17.4 p.p.m.
Sterilized	10.8 p.p.m.	7.0 p.p.m.

Mr. Van Brocklin commented on these analyses as follows:

Any apparent increase in total nitrogen in the soils after irrigation treatment may or may not be real. It may be due to the multiplication of error in calculations from analytical data, the latter not necessarily ultra refined.

However, with the ammonia nitrogen and also the nitrate nitrogen the difference is great enough to be real. In the natural soil there seems to be a falling off in the amount of the former form after incubation in moist condition, while in the sterilized soil there is an increase under similar treatment. The reasons for these differences may be assumed, but further investigation is necessary for actual proof.

With respect to the nitrate nitrogen, the amount seems to be constant in the natural soil, but a loss is indicated in the sterilized soil after periodic watering.

Mr. Van Brocklin also performed citric soluble analyses on Makiki and Kailua soils, steamed and natural, immediately after treatment, and of similar units both planted and unplanted, after a period of approximately three months. There appeared to be no significant change in the content of the citric soluble nutrients, silica (SiO_2), lime (CaO), potash (K_2O), and phosphoric acid (P_2O_5), either as a direct result of steaming or cumulative after incubation of the steamed soils.

Though improbable, it is not to be overlooked that the similar beneficial effects of steaming and chemical fumigation on plant growth may not be due to exactly the same causes (31).

The unused portions of the four soil samples analyzed by Mr. Van Brocklin were used for an observation test and planted with Guam corn and soy beans. The latter were included for observation of response to sterilized soil since the statement was made in one of the Rothamsted reports that all plants except legumes show improved growth in steamed and fumigated soils.

Sixteen small terra cotta pots were steam sterilized and four pots filled with each of the four soil samples respectively which had been analyzed previously by Mr. Van Brocklin. Four seeds of Guam corn and four of soy beans were planted respectively in each of two pots of each soil. (See Table III.) All of the seed germinated and all but one seedling per pot was rogued soon after germination.

TABLE III

Soil Sample	Previous Treatment	Plant
1	Steamed three hours; analyzed the following day; remainder retained in dry condition until Sept. 10, 1932.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
2	Natural soil, control on 1, kept dry until Sept. 10, 1932.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
3	Steamed the same as sample 1, incubated in moist condition six weeks before analysis.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.
4	Natural soil, incubated in moist condition six weeks before analysis.	A. Guam corn.
		B. Guam corn.
		C. Soy bean.
		D. Soy bean.

Fig. 5. Soy bean plants in duplicate series.
First pair grown in steamed Makiki soil, incubated dry before planting.
Second pair grown in natural Makiki soil, incubated dry before planting.
Third pair grown in steamed Makiki soil, incubated wet before planting.
Fourth pair grown in natural Makiki soil, incubated wet before planting.
Note evidence of depressed growth in the first pair.

The following summary of observations made when the plants were 1½ months old, is quoted from an unpublished progress report dated October 25, 1932:

1. There was marked improvement in the growth of the corn seedlings in the steamed as compared with the unsteamed soil in the samples held dry as well as in those incubated in moist condition. In the steamed soil the growth was noticeably more vigorous in the soil which had been incubated in moist condition in contrast to the soil steamed and held in dry condition.

2. The soy beans showed no such improved growth in the steamed soils. On the contrary, those in the steamed soil which had been incubated dry soon showed evidence of distress (Pots 1 C, 1 D). The symptoms manifested were chlorosis of the leaves and depressed

Fig. 6. Guam corn grown in soils treated identically with those in Fig. 5. Note response to steamed soil in the first and third pair.

growth for a period of about two weeks, at which time a new series of normal green leaves developed at the top. The lower leaves remained chlorotic, yellowed and irregularly spotted with brown. None of the other series of soy beans showed any deviation from normal. At this time the soy bean plants in all series were uniform in size, those with the chlorotic lower leaves being a trifle more spindling in growth habit. All were developing fruit.

3. Mr. Van Brocklin's report shows that in the soil analyzed immediately after steaming nitrate nitrogen was reduced from 17.3 p.p.m. to 10.8 p.p.m. and ammonia nitrogen was increased from 16.4 p.p.m. to 27.6 p.p.m. In the steamed soil, incubated six weeks in moist condition, a further increase of ammonia nitrogen to 40.9 p.p.m. was found while the natural soil showed a reduction from 16.4 p.p.m. ammonia nitrogen to 5.9 p.p.m. The nitrate nitrogen in the natural soil incubated moist remained constant while in the steamed soil similarly treated the amount was further reduced from 10.8 p.p.m. to 7.0 p.p.m.

We may infer from the temporary poor growth of the soy beans in the steamed soil which had been incubated dry, in contrast to the normal growth in steamed soil incubated in moist condition, that some product harmful to this plant is formed in soil by steaming. This harmful product is dissipated in about two weeks when the soil is wet.

The photographs, Figs. 5 and 6, were taken November 26 when the roots were examined after the experiment was concluded. They were not taken at a suitable time to show the depressed top growth of the soy beans, or the most marked increase in growth of the Guam corn in steamed soils. The growth in the various units had become more uniform as the better plants had reached a maximum size for the pots and the weaker plants had gradually caught up. However, the increased root growth of the Guam corn in steamed soil and the weaker root system of the soy beans in the sterilized soil, incubated dry, was still evident as shown in Figs. 5 and 6.

The experiments conducted at the Experiment Station by Webster and the writer regarding the causes of improved growth of cane in sterilized or fumigated soils indicate that this growth response is due to increased liberation of ammonia. Just how this is brought about is not clear. The conclusions of Russell and his associates after a thorough study of various phases of the subject extending over several years are the most logical (see p. 289).

Abnormal Nutrition as a Factor in Pythium Root Rot of Cane

An attempt was made in 1928 to develop a suitable working theory for research concerning the controlling factors of *Pythium* root rot. We knew that the fungus concerned was of general occurrence even on varieties which seldom showed distress. An explanation of the erratic occurrence of growth failure was needed. Our records extending over a period of more than thirty years were searched meticulously, keeping in mind a selected group of the observations which appeared more significant. Finally, a theory of excess of nutrients or unbalanced nutrition was entertained as possibly applicable throughout the diverse conditions where the disease occurred.

Excess of Nitrogen: The interrelations of the nitrogenous group of nutrients were considered to be the most likely field for first attention. The reasons for selecting the possible influence of an excess of nitrogen, and of unbalanced nutrients, on susceptibility of roots to *Pythium* attack have been discussed already

Fig. 7. Root systems of Lahaina cane grown in virgin soil. 1. Virgin soil. 2. Virgin soil 75 per cent, compost 25 per cent, by volume; serious root rot. 3. Virgin soil 50 per cent, and cane compost 50 per cent; complete destruction of roots, and death of shoots.

with reference to significant observations in our records of Lahaina failure (10, pp. 279-284).

Experiments promptly revealed that in the theory adopted we had a field of research pertinent to the fundamental cause of root rot. The evidence indicated a predisposition of cane varieties to root rot in diverse degrees, associated with certain idiosyncrasies of absorption of nutrients which led in these varieties to susceptibility to *Pythium* attack. It was found that sodium nitrate, in excess, greatly increased root rot of Lahaina cane in sick soils and induced it in normal soils. In virgin soil, Lahaina cane grew normally without root rot, but, following the addition of moderate amounts of cane compost (trash composted with "Adco") *Pythium* root rot became serious. Larger proportions of compost resulted in total destruction of the roots and death of the plants. (Fig. 7.) Later, it was shown that Lahaina grew even better in compost alone, without root rot, than in virgin soil alone, but that root rot was severe in virgin soil mixed with an equal quantity of compost. Curiously enough, H 109 grew better in a mixture of equal amounts of soil and compost, than in either compost, or soil, alone. Quoting from the writer's annual report (16, p. 39):

> The apparent correlation of fertilizer practice, with special reference to nitrogen, and the decline and failure of the Lahaina variety has also been pointed out. That H 109 cane might similarly fail if nitrogen was economical and desirable at greatly increased applications above present practice is indicated by pot experiments.
>
> An experiment has shown that in pathology plot soil where root disease of Lahaina is not ordinarily a factor, rotting of the roots of this cane became serious when nitrogen in the form of sodium nitrate was added to the soil before planting in excess of 60 pounds per acre. In the series which received nitrogen at the respective rates of 40 and 50 pounds, scarcely a trace of root rot was found and then only an occasional root was affected. The experiment comprised duplicate series with gradually increasing amounts of nitrogen from 0 to 300 pounds per acre. It will be recalled that previous to the first reports of Lahaina failure, in the year 1896 or thereabouts, nitrogen was not emphasized particularly as a fertilizing element. Approximately 40 pounds of this element per acre in the commercial mixed fertilizer was possibly an average application. Following the date mentioned, fertilizer analysis became more general and nitrogen fertilization received more and more emphasis. Large increases of nitrogen applied per acre were suddenly made in some instances; significantly so on one plantation where Lahaina failed spectacularly (1910 and thereafter). Although excess of nitrogen for Lahaina in some way induces root rot, the exact relation of this element to the root disease is not clear.
>
> Root rot of E. K. 28 increased rather than diminished in a test with gradually increasing amounts of molasses, applied as a possible corrective amendment to Waipio sick soil. The cuttings were planted after incubation of the amended soil for two weeks. The result was in harmony with previous experiments with Lahaina cane and "molashcake" soil amendments. In pot tests, the variety P.O.J. 2878 has shown a resistance to *Pythium* root disease comparable to that of H 109. The growth of this variety in the field at Waipio and elsewhere confirms the above observation derived from the pot experiments of October, 1929.

It was soon demonstrated that cane residues, such as compost, were not essential to the development of increased susceptibility. Not only sodium nitrate but stable manure brought on the same condition. Subsequent experiments showed that the resistance of H 109 roots could be overcome by growing the cane in mixtures of soil with 25 to 75 per cent of stable manure. Root rot of Lahaina was induced in a "healthy" soil by amendments with molasses and press cake, incorporated, and the mixture incubated several weeks before planting. No collapse

of Lahaina roots occurred in soil amended with compost or manure and steam sterilized before planting; heavy amendments with these materials did not *per se* cause root collapse or growth failure. When a Lahaina sick soil (from Olaa) was diluted progressively with a healthy soil, *Pythium* root rot became less severe (15, p. 93). With a half-and-half mixture, marked improvement of root health was observed. In mixtures containing less than 20 to 30 per cent of sick soil, *Pythium* root rot became inconsequential.

As a result of these research skirmishes, it was inferred that the controlling factor accessory to *Pythium* as the active agent of root decay, is the type of root

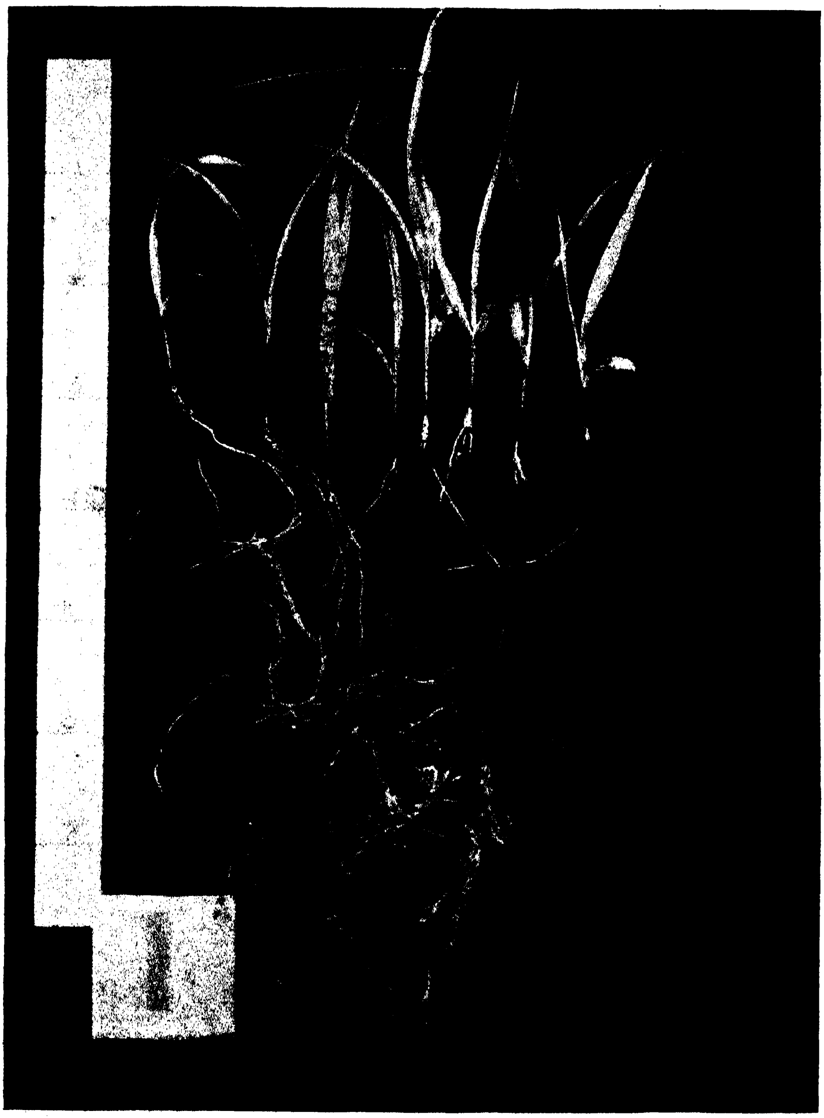

Fig. 8. Sudan grass grown 21 days in phosphate-fixing soil from Hamakua. Plants shown in Figs. 8 to 12 were fertilized with nitrogen, phosphate and potash, but not sufficiently to insure growth in Hamakua soil, sterilized, comparable with that in Makiki soil. (Figs. 11 and 12.)

growth as determined by stimulative nutrients. Quoting from the writer's annual report for 1931 (17, p. 51):

The relationship of stimulative nutrients to *Pythium* root disease, demonstrated in pot experiments during the years 1928 to 1930, was further confirmed by the correction of a growth failure area at the pathology plot. The variety E. K. 28 has been induced to grow normally for about one and one-half years where it formerly failed miserably. The normal growth followed the simple expedient of depleting the stimulative soil nutrients. This was accomplished by growing H 109 and H 146 for 15 months without added fertilizer in the same furrows where E. K. 28 had failed. The variety E. K. 28 was then planted again.

Vanterpool and Truscott (56, p. 89) may be quoted, regarding the relation of nitrogen to wheat root rot, as follows:

Carpenter contends that *Pythium* root rot of sugar cane in Hawaii is enhanced by nitrogenous decomposition compounds of sugar cane factory by-products and by excess nitrate;

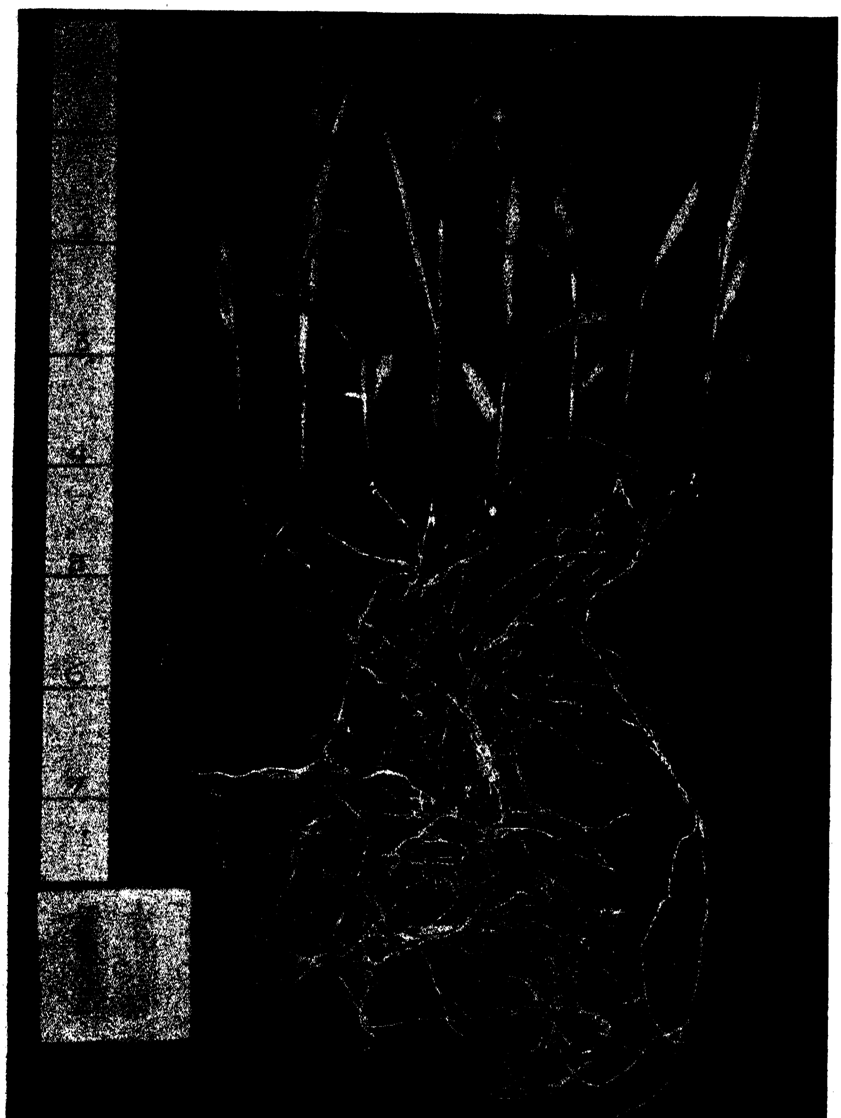

Fig. 9. Sudan grass grown 21 days in chloropicrin-treated soil from Hamakua.

also that bagasse or pure sugar cane fibre inhibits the disease. Our greenhouse experiments coupled with the knowledge that the nitrate nitrogen is highest when browning root rot is worst, and that on the stubble crop nitrate nitrogen is low when browning root rot is practically absent, suggest that Carpenter's view may hold for browning root rot of wheat also. This is only suggestive as present results are indefinite and inconclusive; it remains for fertilizer experiments in naturally infested fields to prove or disprove this view.

Walker (58) studied the relation of fertility to the similar disease, *Aphanomyces* root rot of peas. He stated that eight canning varieties were tested in the greenhouse on this type of soil from a heavily infested field. All were severely damaged by root rot which underwent a marked decline on the addition to a portion of the soil of a 500-pound application of 4-16-4 fertilizer.

Pythium Root Rot in Phosphate-fixing Soils: Cooke (20) has reported studies of growth failure of cane in phosphate-fixing soils and the steps in his investiga-

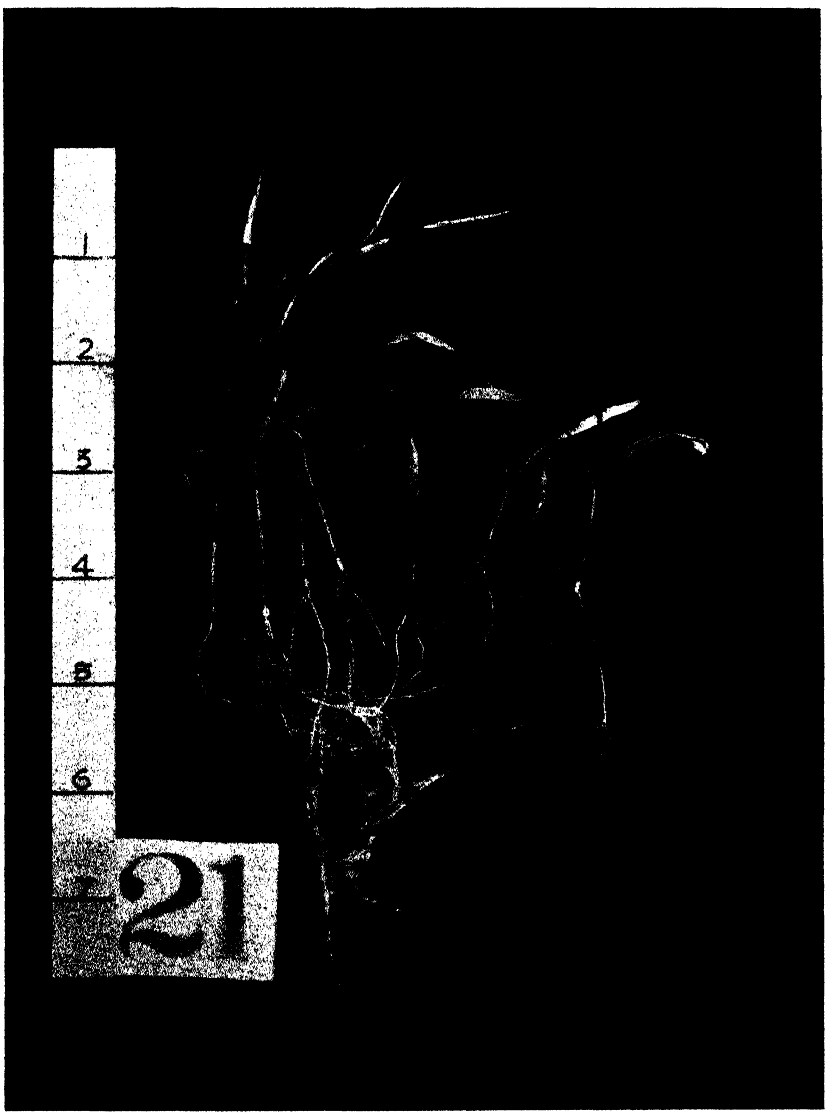

Fig. 10. Sudan grass grown 24 days in steamed soil from Hamakua.

tion which led him to believe that biological factors were concerned. He found that either of two treatments, high phosphate applications or chloropicrin fumigation, gave improved growth of Sudan grass in the phosphate-fixing soils of Hamakua Mill Company. His chemical tests failed to detect any changes of pH of the soil or chemical solubility and availability of nutrients attributable to the action of the chloropicrin. Neither was there any evidence obtained that chloropicrin fumigation of soil resulted in a direct stimulation of plants grown therein. He also pointed out that with normal soil containing adequate amounts of available phosphate, no improvement resulted from chloropicrin fumigation or phosphate applications.

Mr. Cooke's insistence that biological factors were indicated by his investigations led to a more active cooperative endeavor to solve the problem. (Figs. 8-12.)

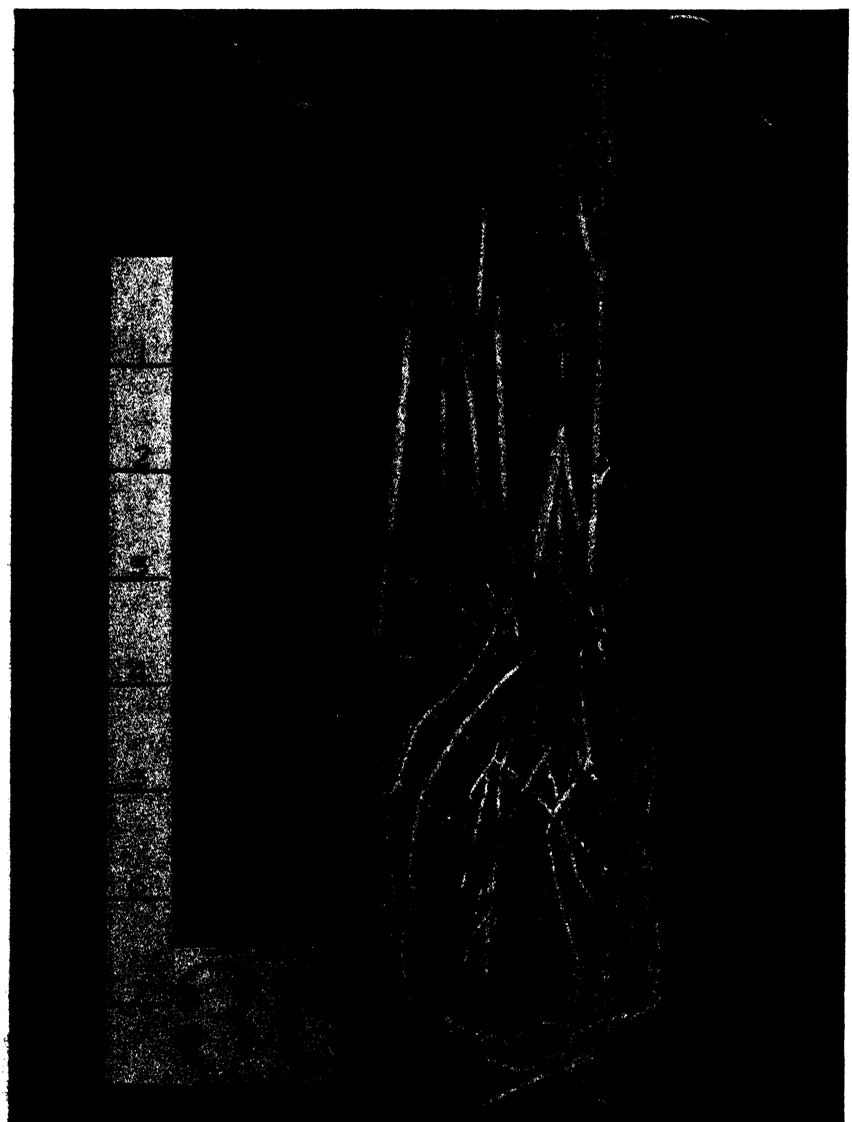

Fig. 11. Sudan grass grown 24 days in Makiki soil.

A dilution test, such as the writer mentions elsewhere in this paper (p. 293), was conducted by Mr. Cooke.

This experiment contained chloropicrin-treated soil and mixtures of treated soil respectively with 1/5, 2/5, 3/5 and 4/5 of untreated soil as well as units of untreated soil. The writer (15, pp. 93, 94) had found similar dilution tests very useful as basic experiments in soil studies to obtain indications whether growth failure problems were biological or malnutritional (excesses or deficiencies). Cooke's (l.c., p. 171) observations of this test are quoted as follows:

Now, if these pots showed a tendency for quantitative increase from the untreated to the chloropicrin-treated pots, we might expect that the effect on the soil was chemical or physical. This did not occur. Only the pots with all sterilized soil showed a gain. . . . The rest of the pots whether containing 4/5 unsterilized, 1/5 unsterilized soil or all unsterilized soil, showed

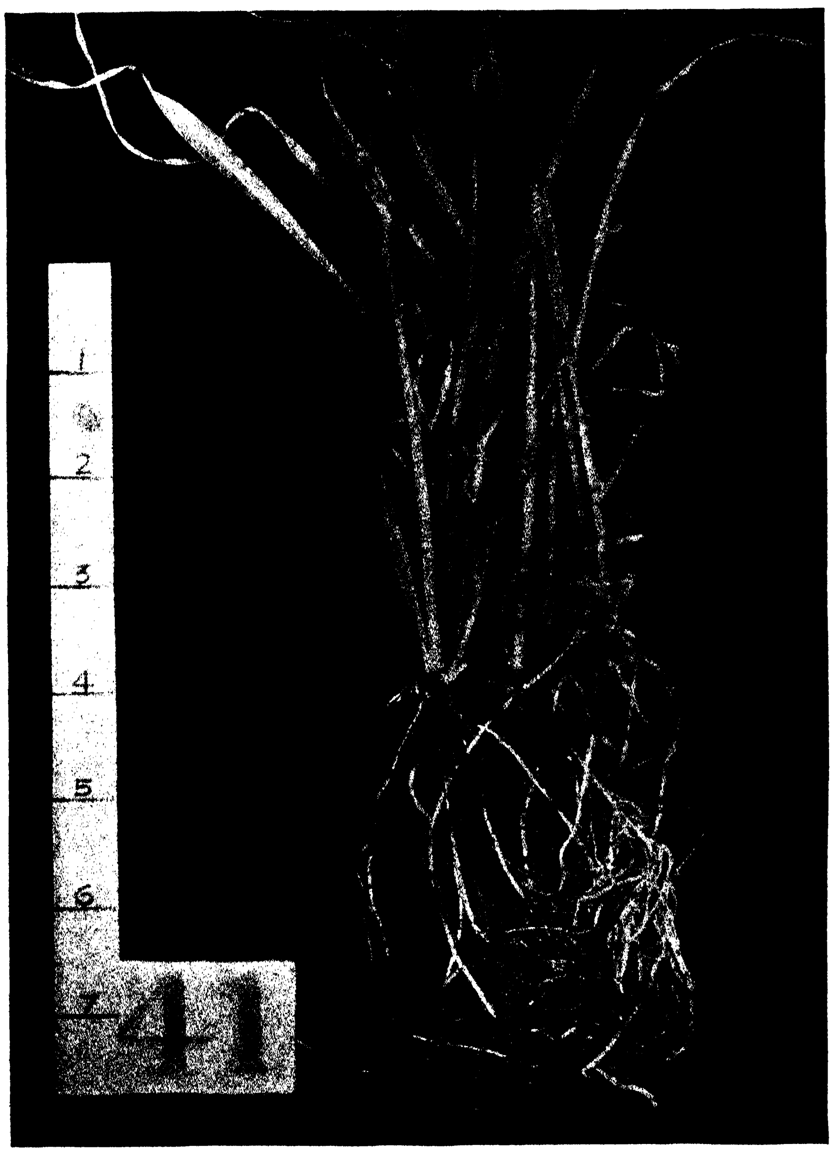

Fig. 12. Sudan grass grown 24 days in chloropicrin-treated Makiki soil.

an equal depression in growth. This fact that only 1/5 of the soil being unsterilized could reinfect it and check the growth as effectively as untreated soil, clearly indicated some living soil organism that was destroyed by complete sterilization. A similar test on the subsoil of this field showed exactly the same thing.

As Cooke has stated (l.c., p. 172) the writer found in a preliminary survey of bacteria, fungi and actinomycetes in treated and untreated soil, that the numbers of all three types were greatly decreased by chloropicrin treatment. The number of organisms were not determined again after incubation of the samples.

Examination of roots of Sudan grass in untreated Hamakua soil in Cooke's experiment revealed at once large numbers of oospores and prosporangia of *Pythium* (illustrated in an unpublished report dated April 29, 1933). This fungus was identified from pure cultures as the cane *Pythium,* which we have called *P. aphanidermatum,* but which will hereafter be referred to as *P. graminicolum,* for reasons given on page 288.

The investigation of the "phosphate-fixation *Pythium*-root-rot complex" was conducted jointly with Cooke. It was demonstrated in Mitscherlich pots with both Sudan grass and cane of several varieties that depressed growth resulted when pure cultures of the *Pythium,* isolated from diseased cane roots collected in Hamakua, were added to chloropicrin-treated soil from the same field.

It was also demonstrated by experiments that this depression of cane growth following *Pythium* inoculation of chloropicrin-treated soil, corresponding to that

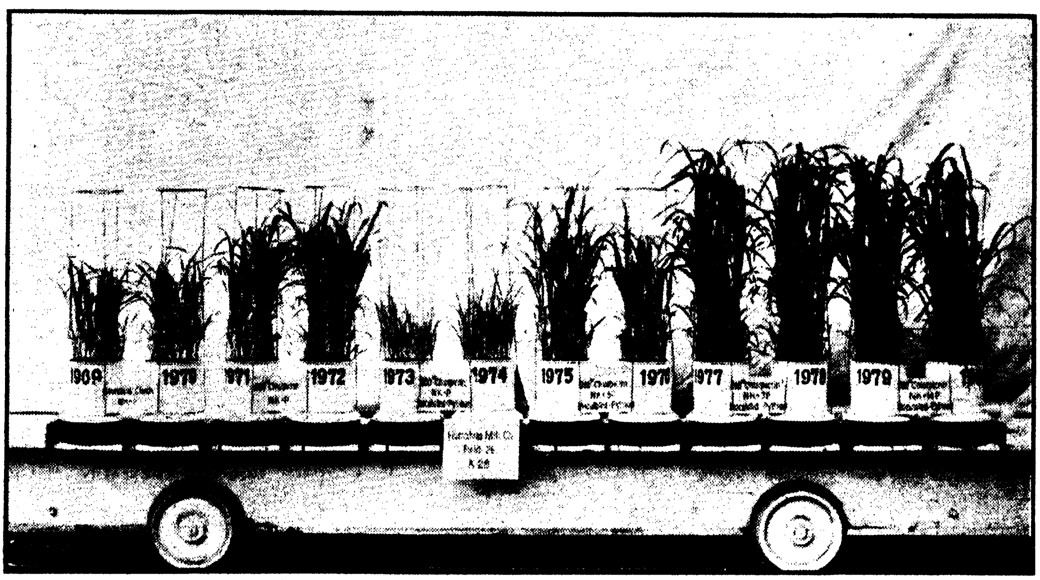

Fig. 13. Test with Sudan grass on soil from Hamakua, Field 26. Reading from left to right—two pots check with N-312, K_2O-426, and P_2O_5-426 pounds per acre; two pots same fertilizer + chloropicrin (200 pounds per acre); two pots same fertilizer + chloropicrin (200 pounds per acre) + *Pythium* sp.; two pots same N and K + chloropicrin and *Pythium,* but 1278 pounds P_2O_5 per acre; two pots same N and K + chloropicrin and *Pythium,* but 2982 pounds P_2O_5 per acre; last two pots same N and K + chloropicrin and *Pythium* but 5960 pounds P_2O_5 per acre. The depression from adding *Pythium* can be seen in pots 1973 and 1974; 1975 and 1976 show that phosphate can overcome the effects of the *Pythium* and especially with the high amounts excellent growth is obtained.

naturally occurring in the untreated soil, could be corrected by heavy applications of phosphate. A discussion of a typical experiment is quoted from Cooke (l.c., p. 173) as follows (Cooke's Fig. 2 is reproduced as Fig. 13):

. . . Mr. Carpenter, using the Mitscherlich pots, was thus able to reproduce the growth failure on chloropicrin-sterilized soil by inoculation with a pure culture of *Pythium*. In an attempt to determine the relationship between high amounts of phosphate and chloropicrin an experiment was also started with the following make-up of treatments and pots.

2 pots usual N-P-K
2 pots usual N-P-K + 200 pounds chloropicrin per acre
2 pots usual N-P-K + 200 pounds chloropicrin + pure culture *Pythium*
2 pots N-K 3P + 200 pounds chloropicrin + *Pythium*
2 pots N-K 7P + 200 pounds chloropicrin + *Pythium*
2 pots N-K 14P + 200 pounds chloropicrin + *Pythium*

Fig. 13 shows this test at the start. The increase when the soil was sterilized with 200 pounds of chloropicrin is apparent. The next treatment shows that when *Pythium* was added, the depression at the beginning was even greater than the original poor growth. This was only temporary, however, because at the end of the test, when 68 days old, the two treatments were almost exactly the same. When three times the usual amount of phosphate is added to this chloropicrin-treated and *Pythium*-inoculated soil the response is practically the same as with chloropicrin. Higher amounts of phosphate up to 21 grams per pot give even better growth.

A brief survey of the fields at Hamakua Mill Company where cane roots were collected by the writer and examined microscopically showed the *Pythium* fungus to be common in the rotting roots where cane growth was depressed. Studies of cane root systems were then conducted in soil from Hamakua in root observation boxes and glass percolation cylinders. (Figs. 14, 15, 16.) The following is quoted from a progress report:

Comparison of the four varieties of cane, U. D. 1, Natal Uba, D 1135 and P.O.J. 36, in chloropicrin-treated and untreated soil from Field 26 K, Hamakua Mill Company: Two kgms. of soil were placed in each of eight glass percolation jars. One cc. of chloropicrin was added to the soil of each of four of the jars, the top of the jars sealed with paper, and fumigation continued for three days. Three days after removing the paper seal, the eight jars were planted in duplicate series of treated and untreated soil with short-joint cuttings of the mentioned varieties. This small experiment consistently provided striking differences in root development and root collapse in untreated vs. treated soil with all four varieties.

All varieties developed a much more extensive root mass in the chloropicrin-treated soil corresponding to the better top growth therein. Root rot of the *Pythium* root disease type was conspicuous with all four varieties in the untreated soil. After about two months, the soil was carefully washed from the roots and the latter examined. The poor condition of the roots and the depressed aerial growth in the untreated soil appeared to be directly due to the root disease. Even the roots which had not collapsed were invaded by the fungus and subject to progressive collapse. P.O.J. 36 appeared to be somewhat less seriously affected than the other three, Natal Uba, U. D. 1 and D 1135. In contrast, the growth of the four varieties in the treated soil indicated that, for the period under survey, in the absence of root rot, sufficient nutrients for normal development were available.

Comparison of five varieties of cane grown in untreated soil and with compost amendments: In experiments several years ago, it was observed that compost amendments tended to aggravate *Pythium* root collapse in soils well supplied with nitrogen. It was thought that the effect of compost on root disease in soils considered deficient in phosphate might be beneficial. The fact that the growth and root health of the varieties, P.O.J. 36, U. D. 1 and

Fig. 14. Cane of four varieties growing in chloropicrin-treated and untreated Hamakua soil, respectively, age two months. From left to right: Natal Uba, treated and untreated; D 1135, P.O.J. 36 and U. D. 1. Note evidence of improved root growth.

Natal Uba, were greatly benefited might have been foreseen, but the reaction of P.O.J. 2878 was surprising. This variety apparently made a normal growth on the unamended soil corresponding favorably with that in 25, 50, 75 and 100 per cent compost. (See Figs. 18 and 19.)

Root study boxes with glass sides were used for this experiment. Soil and mixtures of soil and well-rotted compost were planted with cuttings May 3. The varieties included were U. D. 1, Natal Uba, D 1135, P.O.J. 36 and P.O.J. 2878. One cutting of each variety was planted in each box of a series containing the following items:

1. Soil.
2. Soil 75 per cent, compost 25 per cent, by volume.
3. Soil 50 per cent, compost 50 per cent, by volume.
4. Soil 25 per cent, compost 75 per cent, by volume.
5. Compost.

Fig. 15. Natal Uba and D 1135 grown in phosphate-fixing Hamakua soil. (See Fig. 14.)

1. Natal Uba, chloropicrin-treated soil.
2. D 1135, chloropicrin-treated soil.
5. Natal Uba, untreated soil.
6. D 1135, untreated soil.

Observations from time to time showed that the varieties U. D. 1, Natal Uba and P.O.J. 36 were growing very slowly in the unamended (unfertilized) soil and that this restricted growth (as compared with P.O.J. 2878) was accompanied by badly rotting root systems. D 1135 failed to germinate in the unamended soil. With all varieties except P.O.J. 2878 (and D 1135, which failed to germinate, as above noted) there was a marked improvement in growth in the mixture containing 25 per cent of cane compost, accompanied by much more vigorous root systems. (Fig. 17.) The striking contrast between the depressed growth in the soil alone and the improved growth in the compost mixtures did not appear to be the sole result of differences in available nutrients. The correlation of root health with vigor of the plants appeared to account largely for the differences, especially when considered in contrast with the vigor of P.O.J. 2878 in the unamended soil. (Fig. 18.) This variety seemed to grow normally from the time of germination in the unamended soil and the plants supplied with compost did not grow materially better (Fig. 19). Apparently this variety, not suffering from root curtailment, found sufficient nutrients for its needs either from the cuttings or from the soil.

The soil was washed from the roots about 2½ months after planting. U. D. 1, Natal Uba and P.O.J. 36 were severely affected with root rot in the soil alone. Root collapse of these varieties was of minor significance in the soil plus 25 percent compost. The amount of root failure in D 1135 by comparison in the latter soil mixture, indicated a greater weakness of this variety. Unfortunately, a direct comparison of the D 1135 in amended and unamended soil was not available since this variety failed to germinate in the latter.

The poor growth of U. D. 1, Natal Uba and P.O.J. 36, accompanied by severe root collapse in the unamended soil, considered in comparison with the growth of P.O.J. 2878 with its healthy and extensive root systems, which revealed but traces of root rot, appeared to be directly due to *Pythium* root rot. The fact that P.O.J. 2878 did not benefit materially from the increasing amendments of compost or the compost alone indicated approximately a maximum growth in the unfertilized soil. If we conservatively assume that the growth of all varieties for the period under survey was from the nutrients stored in the cuttings, which were of approximately the same size in the respective varieties, we still have to account for the depressed growth of U. D. 1, Natal Uba and P.O.J. 36 in the unamended soil, in contrast to P.O.J. 2878.

The combined evidence from the experiments thus far considered indicates that the depressed growth—of young cane at least—is due to root rot rather than to any deficiency of available nutrients *per se*. The experiments confirm the program of investigations along the practical lines of variety tests and specific fertilization to increase the resistance of the root systems to *Pythium* root rot.

It was obvious that Sudan grass and young cane plants obtained sufficient phosphate for normal growth in the phosphate-fixing soil after it was treated with chloropicrin. It appeared probable that for young plants, in the absence of *Pythium,* there was sufficient available phosphate in the soil or carried by the cuttings to permit normal development but that in the presence of *Pythium,* there was insufficient phosphate to insure resistance. Mr. Cooke had already grown Sudan grass in cultures in quartz sand treated with chloropicrin vs. untreated sand and was unable to detect any stimulating or nutritional effect of chloropicrin.

Another observation experiment was conducted to note if chloropicrin were merely a sterilizing agent or if it had some direct action on the "phosphate-fixation complex" not possessed by other sterilizing agents. Percolation cylinders were used to grow P.O.J. 36 cane in Hamakua soil, one-eye cuttings being planted, thus limiting the amount of reserve nutrients. The cuttings were hot-water

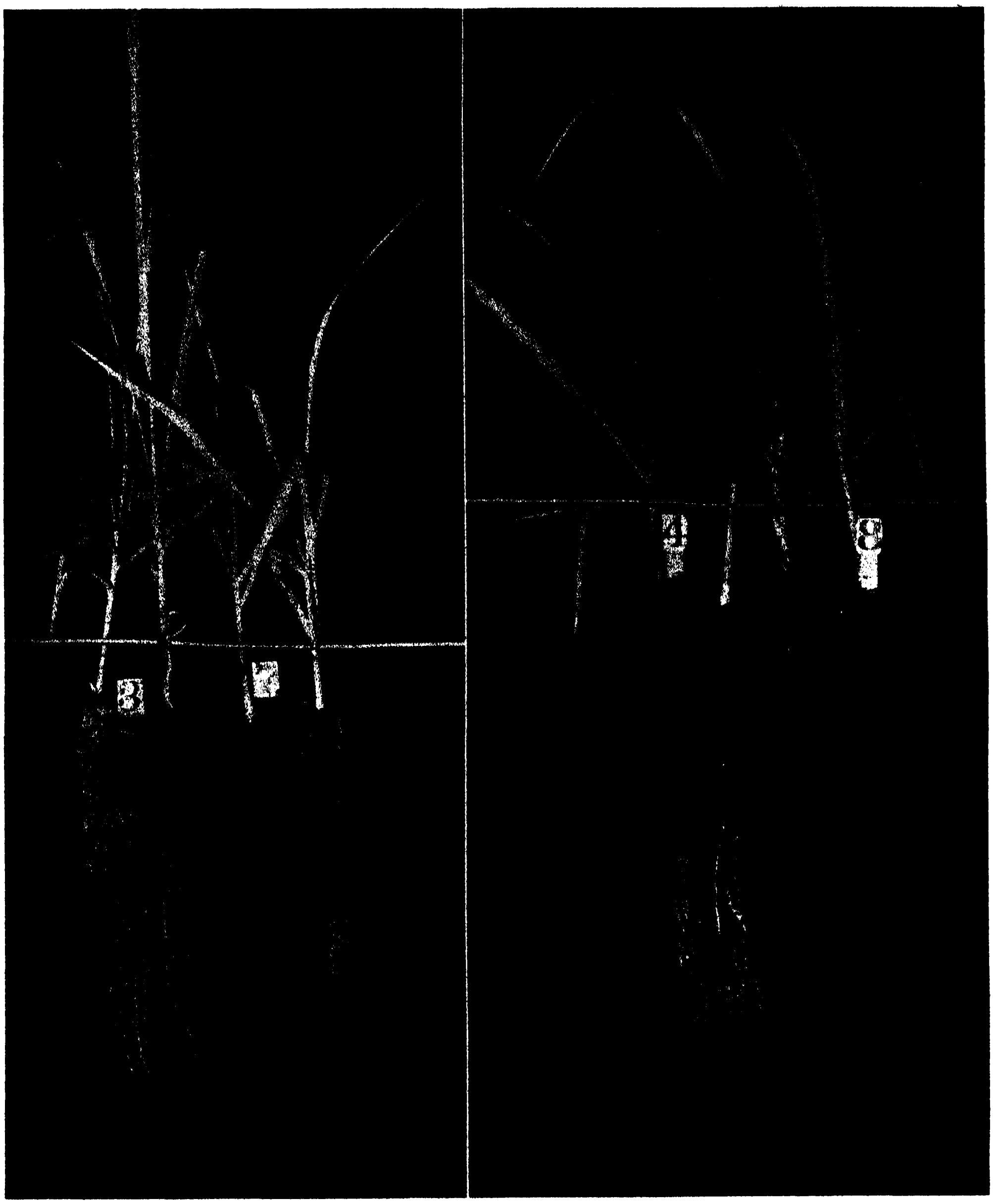

Fig. 16. P.O.J. 36 and U. D. 1 grown in phosphate-fixing Hamakua soil. (See Fig. 14.)

3. P.O.J. 36, chloropicrin-treated soil.
4. U. D. 1, chloropicrin-treated soil.
7. P.O.J. 36, untreated soil.
8. U. D. 1, untreated soil.

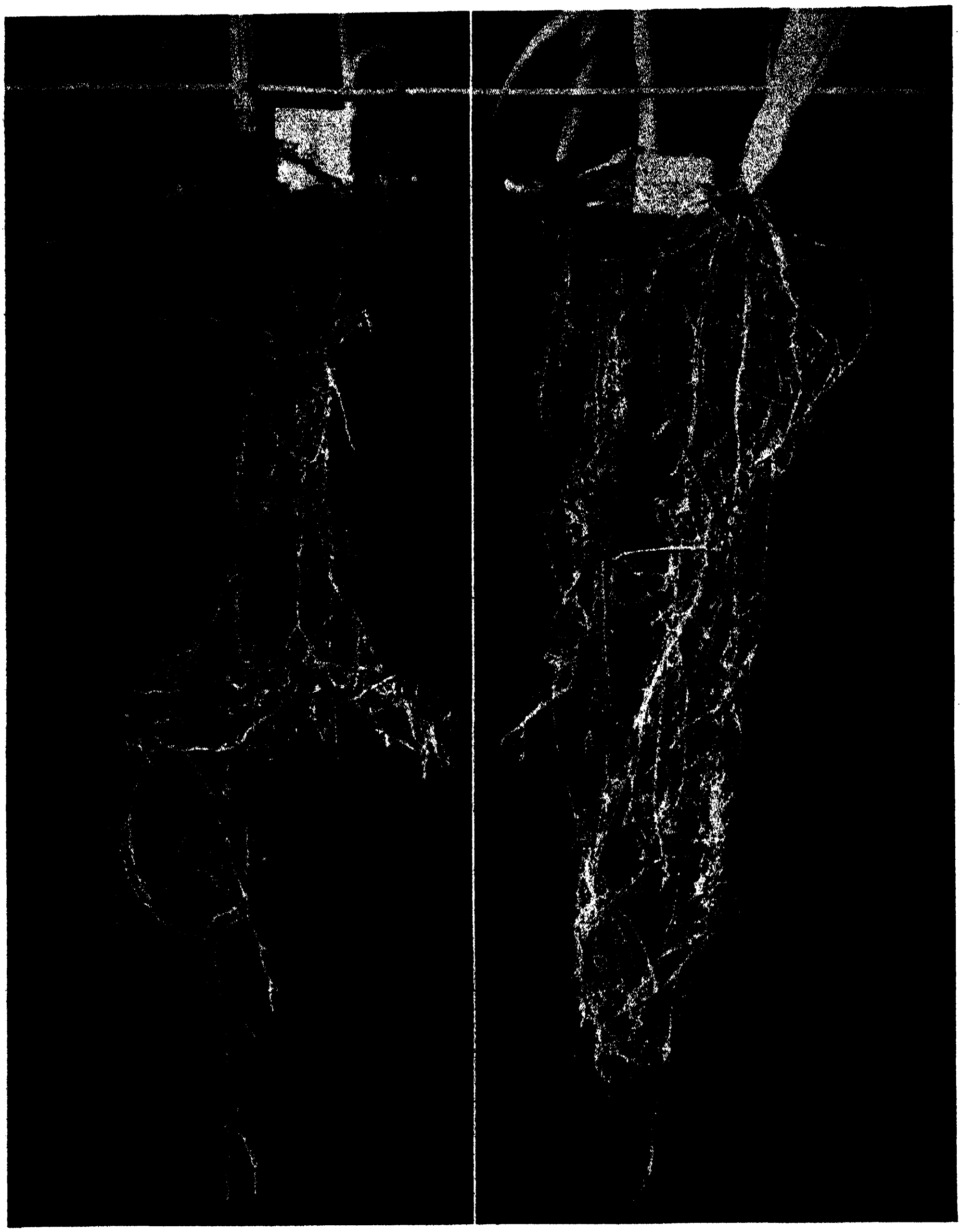

Fig. 17. P.O.J. 36, at left, in unfertilized phosphate-fixing soil from Hamakua; note badly rotted roots. At right, in soil 75 per cent, cane compost 25 per cent, by volume.

treated (52° C. for 20 minutes) and planted September 9, 1933. The experiment included treatments* as follows:

Control					
Chloropicrin	½	cc.	per	kgm.	soil
Toluene	1	"	"	"	"
Carbon bisulphide	1	"	"	"	"
Formalin	3	"	"	"	"
Hydroquinone	0.5	gm.	"	"	"
Steamed soil					

Observations, as well as dry weights of roots and tops showed all treatments superior to the controls. The chloropicrin treatment was duplicated almost to the same degree of improvement by hydroquinone and carbon bisulphide; the toluene, steam and formalin treatments were apparently less effective, or spontaneous infection with *Pythium* occurred to a greater degree. The root growth in the soil treated with hydroquinone was outstanding, the effect apparently being more lasting than with the other chemicals used. The total weight of the superior appearing roots, however, did not equal that in the chloropicrin treatments.

An observation test of the roots of cane varieties in this Hamakua soil was also conducted in glass percolation cylinders. Severed shoots without roots were planted in preference to cuttings, thus reducing the amount and effect of stored nutrients to a minimum. The soil was fertilized with a fertilizing mixture supplemented with sodium nitrate (estimated equivalent to a field application of nitrogen [N] 100 pounds, phosphoric acid [P_2O_5] 200 pounds, and potash [K_2O] 185 pounds per acre).

The amount of root rot observed under the above experimental conditions indicated, in so far as such young plants were a criterion, that the thirteen varieties might be grouped into four classes according to reaction to *Pythium* root rot, as shown in the following table:

TABLE IV

(First 3 weeks' growth)

Susceptible	Moderately Susceptible	Resistant	Highly Resistant
D 1135	P.O.J. 36	P.O.J. 2878	U. S. 996
H 109	P.O.J. 2364	28 - 1234	
U. D. 1		Kassoer	
Natal Uba		28 - 4291	
Badila			
Yellow Caledonia			
(Subsequent growth—3 weeks to 3 months)			
H 109	U. D. 1	P.O.J. 2878	U. S. 996
D 1135			Kassoer
Badila			28 - 4291
Natal Uba			28 - 1234
P.O.J. 2364			
Yellow Caledonia			
P.O.J. 36			

*All of the mentioned treatments except chloropicrin and carbon bisulphide were used by Russell and Buddin (46), and their characteristics described. Toluene is representative of a class of antiseptics that volatilizes completely, while hydroquinone is representative of the non-volatile antiseptics which persist in the soil and modify biological processes. It was thought that these diverse compounds, in the amounts used, would not all act in the same way to increase the solubility of phosphate if such a reaction by chloropicrin was a tenable theory.

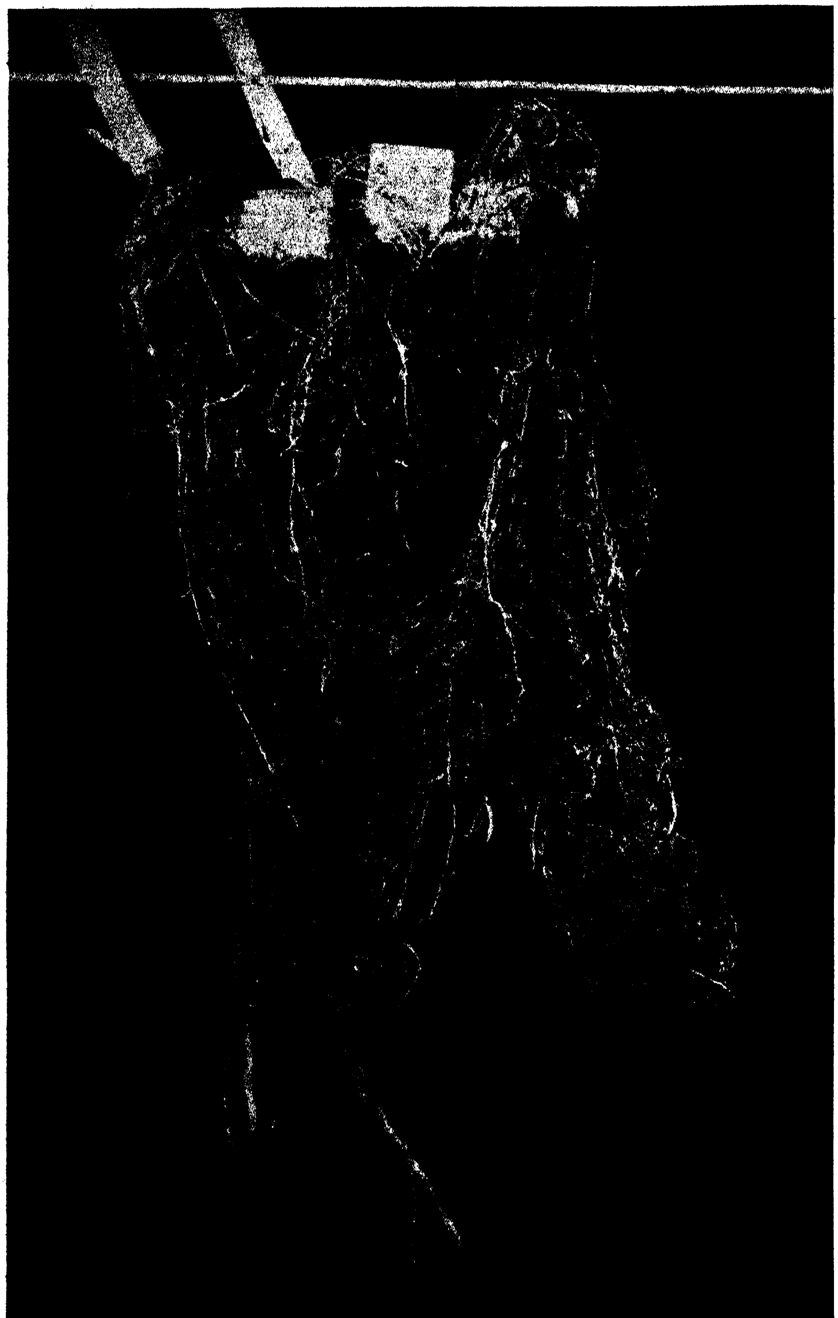

Fig. 18. P.O.J. 2878, in unfertilized Hamakua soil. Compare root system with plant at left, Fig. 17.

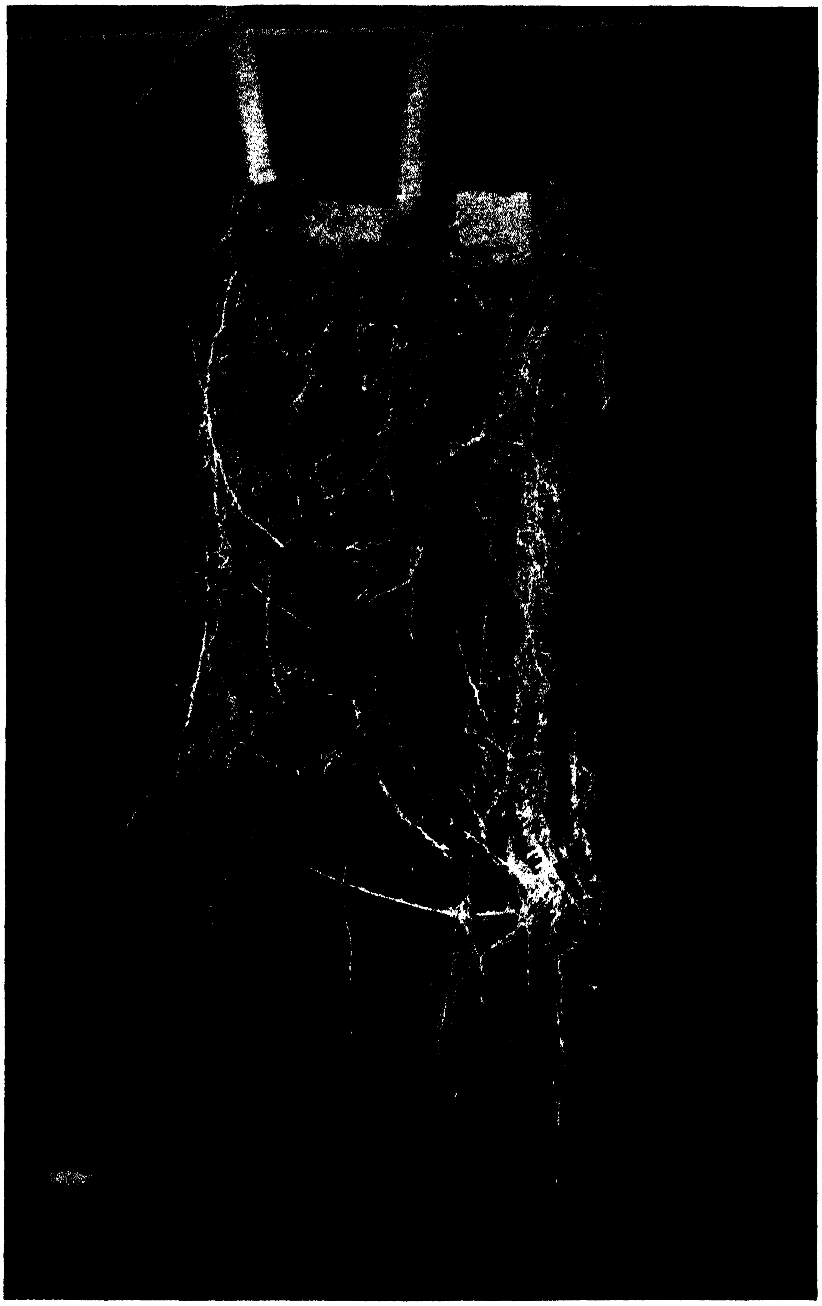

Fig. 19. P.O.J. 2878, in Hamakua soil 75 per cent, and cane compost 25 per cent, by volume. Note lack of response to compost in contrast to P.O.J. 36 in Fig. 17.

Additional plants of the same varieties were also grown in root boxes and 4 months later the root systems were washed free of soil and examined. The observations of the root systems confirmed the grouping in Table IV. The roots of U. D. 1 were badly rotted corresponding to those of H 109 in this phosphate-fixing soil (cf. Figs. 20 and 21). Judging by the root systems, the more resistant varieties were as listed in the table, with H 109 and U. D. 1 the most seriously affected and presumed to be the least resistant. In the variety tests in the fields of Hamakua conducted by the Genetics Department, the varieties U. S. 996, 28-4291 and 28-1234 were considered as most promising types.

"Discriminative root nutrition," by which we mean the nourishing of parts of the root system by various essential elements, offers an interesting subject of study. With reference to phosphate fixation and *Pythium* root rot as a factor in growth depression in such soils, it was thought desirable to learn the effect on the root system of supplying phosphate to one root. In preliminary experiments, several units of unfertilized soil and water cultures of cane in which one root of each plant was led into a solution of sodium phosphate were studied (Figs. 22-25). These cane plants, either in phosphate-deficient soil or in water cultures entirely lacking in phosphate were grown with particular reference to root disease and fertilization, e.g., by the briquette method which is under investigation by the Chemistry Department.

It was interesting to note the following points: (1) The isolated roots in solutions of phosphate alone were normal and grew vigorously with many branch roots. (2) The growth of the plants in phosphate-fixing soil was greatly stimulated. (3) The remainder of the root systems apparently suffered less from root rot than the controls with no outside contribution of phosphate. (4) In water culture, the remainder of the root system was stimulated to a much more vigorous development of perfectly healthy roots (Fig. 25); *Pythium* root rot was serious on the control plants which received no phosphate.

Apparently, the phosphate was assimilated by the one root and benefited the entire plant, while conversely the essential elements other than phosphate absorbed by the root mass served to nourish the isolated root. Additional experiments conducted with Hamakua soil in which one root from D 1135 plants (Fig. 23) growing in the soil was led into phosphate solution resulted in improved growth as compared with control plants (Fig. 22) in soil without external contributions of phosphate. With one root conducted into quartz sand containing a fertilizing briquette (Fig. 24) prepared by the Chemistry Department, greatly improved growth of D 1135 occurred in Hamakua phosphate-fixing soil.

Deficiencies, Excesses and Balance of Nutrients: An attempt was made by Mr. Martin and the writer to substitute tap water for distilled water in culture solutions for certain rough determinations where pure water was not required. Martin (36, p. 31), in commenting on this procedure, is quoted as follows:

> **The total growth failure of plants in water cultures containing nutrient salts dissolved in tap water (pH value=5.8 to 6) was completely corrected by lowering the pH value of the solution to 5 by adding sulphuric acid. Iron was thus made available to the plants because the increased acidity kept it in solution. In the unadjusted solutions, the young plants developed acute iron deficiency symptoms and soon died. In water cultures made up with dis-**

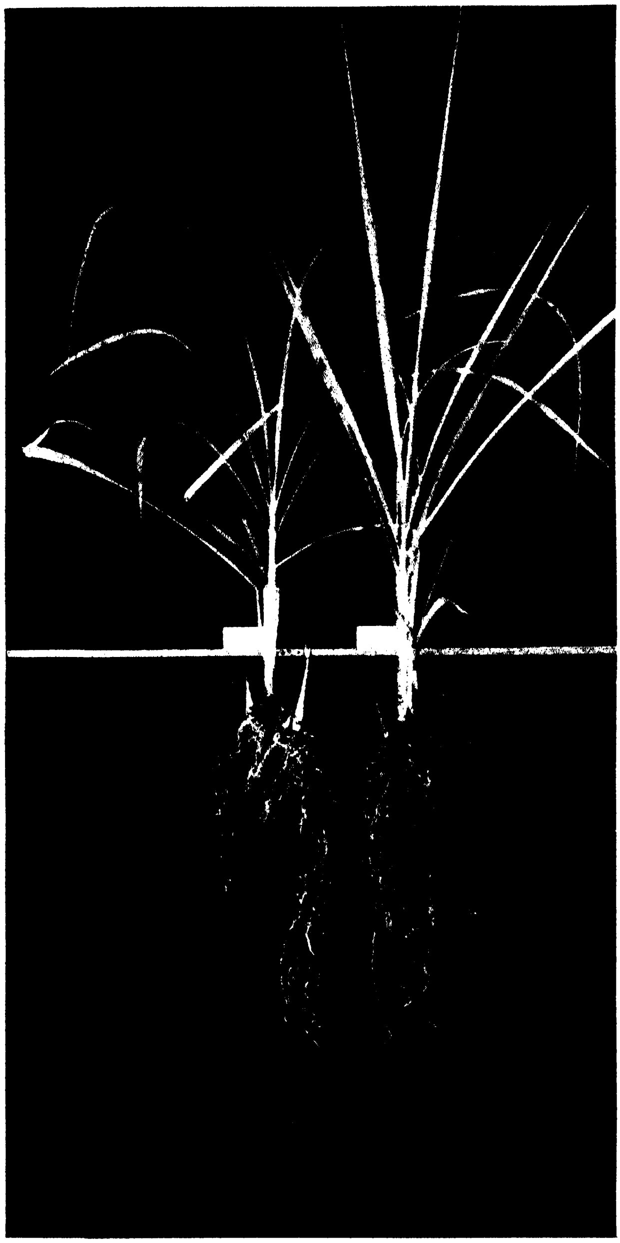

Fig. 20. Roots of U. D. 1 and H 109 grown six months in Hamakua soil (cf. Fig. 21).

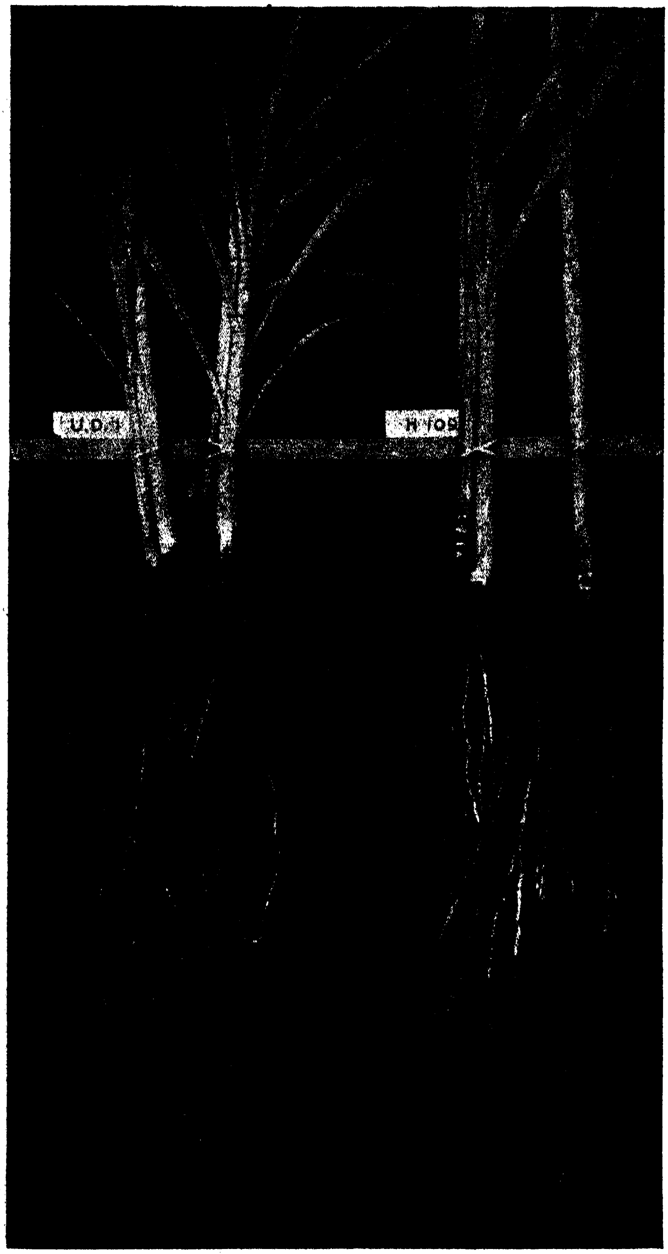

Fig. 21. Plants in Fig. 20, transplanted in Makiki soil and grown five months. (Photographed at the same distance.) Note normal roots, in contrast to deficient, rotted root systems in Fig. 20.

tilled water with the same nutrient salts, the pH values of the solution were 5 to 5.2 and the cane plants made a normal growth.

. . . root damage from parasitic fungi, e.g., *Pythium* root rot, is greatly increased in an ''unbalanced'' nutrient solution. This was particularly true in the plus nitrogen series and in the minus calcium, phosphorus and iron series. These observations are in agreement with the results of soil studies reported by Mr. Carpenter. . . .

Additional confirmation of the relation of nutrients to *Pythium* root rot of cane was observed by Martin (37) in several series of water cultures. The following quotations will summarize his observations on root behavior and *Pythium* root rot as it occurred in solutions deficient respectively in one of the chemical elements essential for cane growth:

Nitrogen deficiency:

The roots appeared to have been stimulated in growth. They attained a much greater length but were smaller in diameter than the roots of the control plants. The root system of each plant completely filled the jar and was extremely free from *Pythium* root rot.

Upon the addition of nitrogen to the minus-nitrogen series, a definite color and growth response was visible within 15 days; it may also be observed that the root system of the H 109 plant . . . lost its compactness following the addition of nitrogen. This condition is due largely to the breaking down of the individual roots from *Pythium* root rot. Carpenter, in 1928, demonstrated that the severity of *Pythium* root rot on cane varieties grown in the soil increases with increased applications of nitrogen. . . .

Iron deficiency:

The roots of the iron deficient plants developed an abnormal type of growth, which later proved to be characteristic of plants growing in a minus-iron medium. The growth of the primary roots was greatly retarded; the secondary roots, as well as those of the third order, were extremely short or ''stubby'' in growth. A large number of roots were killed by *Pythium* root rot indicating that an ''unbalanced'' solution is favorable for the development of this disease.

Phosphorus deficiency:

The roots were decidedly brownish in color and were badly affected with *Pythium* root rot. In recent studies it has been shown that cane roots when grown in water cultures deficient in phosphorus are more susceptible to *Pythium* root rot. Cooke and Carpenter demonstrated that sugar cane is much more susceptible to *Pythium* root rot when grown in soils deficient in phosphorus. . . . In soils low in phosphorus, an abundance of fine or hair-like roots develop, the large roots remaining short and small in diameter.

Sulphur deficiency:

The plants in the minus-sulphur series lacked growth and vigor, when compared with the control plants. The depressed growth was marked at the end of 6 or 8 weeks. A poor root system developed on the plants and considerable damage resulted from *Pythium* root rot.

Manganese deficiency:

Shortly after the leaf symptoms developed, the plants failed to make further growth. The leaf and stalk tissues became soft and ''rubbery'' in texture. Due to this weakened condition, the leaves began to droop and the youngest leaves began to die. The plants, in an effort to continue their growth, developed side shoots but these were also extremely weak. The root systems were in a weakened condition. *Pythium* root rot was present in abundance, and the plants soon died.

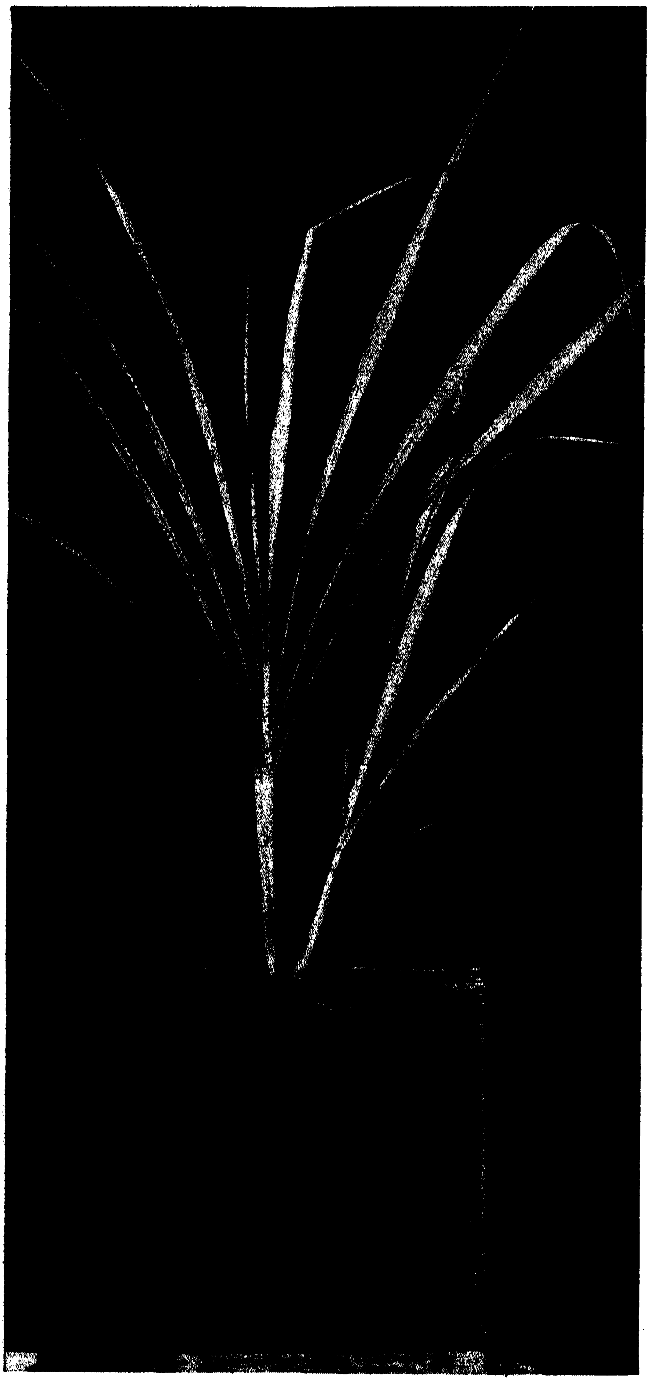

Fig. 22. D 1135 in Hamakua phosphate-fixing soil, control plant for those shown in the following two figures. Fertilized with nitrogen and potash. No outside contribution of phosphate.

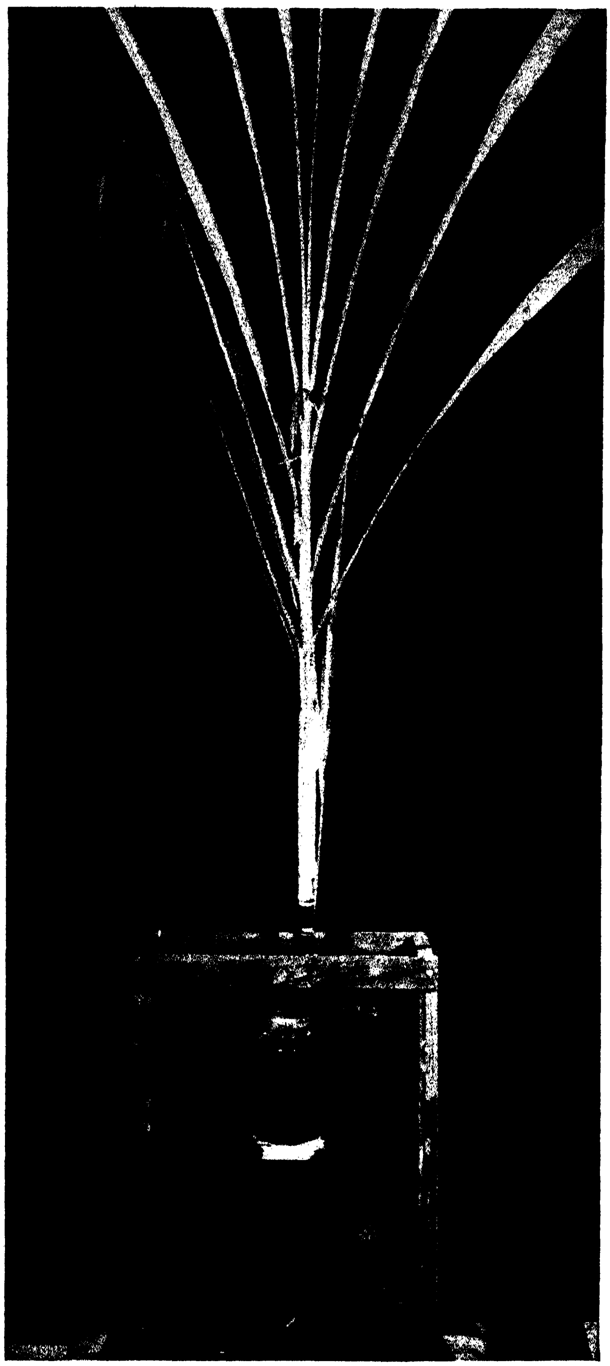

Fig. 23. D 1135. Compare with Figs. 22 and 24. One root was detoured into sodium phosphate solution.

Potassium deficiency:

An abnormal root development resulted in this series. The roots were badly attacked with *Pythium* root rot.

Magnesium deficiency:

Considerable root injury resulted from *Pythium* root rot.

Calcium deficiency:

The effect on the root growth was very marked. Root development was greatly retarded in 2 to 3 weeks after calcium had been omitted from the nutrient solution. The roots became soft and flaccid as a result of *Pythium* root rot. At the end of 8 to 10 weeks, the ro was so severe that practically every root had died. The greatest damage from *Pythium* roo rot occurred in this series.

Thus, it is seen in water cultures that a deficiency of any of the eight elements, except nitrogen, favors spontaneous *Pythium* attack. The amount of nitrogen even in culture solutions appears to exert a controlling influence on root resistance. A lack of calcium was promptly reflected by root collapse.

Albrecht and Jenny (1) found in a series of experiments that "damping off" of soy beans decreased as acidity decreased and calcium increased. The hydrogen ion concentration in itself was considered unimportant, damping off occurring between pH 3.8 and 6.94. The organisms concerned were not identified.

Swanback and Jacobson (52) made the following statement:

Laboratory and field investigations in Connecticut have shown that a form of brown root rot of tobacco *(Thielavia basicola)* is due to the insufficient intake of calcium by the plant. This condition may be induced by lack of available calcium, an excess of magnesium over calcium, or the presence of appreciable amounts of ammoniacal in relation to nitrate nitrogen.

The variety P.O.J. 2878 has recently been subject to an aggravated growth failure in certain fields at Puuloa, Oahu. The appearance of the stunted plants and the occurrence of *Pythium* in the badly rotting root systems have resulted in a diagnosis of *Pythium* root rot. The cane was growing normally in the lower Puuloa or coral fields but was failing on the slopes of the Salt Lake Crater. We might assume that since this variety is not considered to be sensitive to either nitrogen excess or phosphate deficiency, that the susceptibility may be induced by deficiencies of one of the elements essential for growth, e.g., calcium, iron, etc., mentioned on pages 325, 328. A good response of P.O.J. 2878 to chloropicrin fumigation of the soil in pot studies was obtained and indications of response to small applications of calcium sulphate.

The effect of excesses of the various elements, except nitrogen, in the soil has not received adequate attention. One soil observation indicated that applications of friable coral to a portion of a field in changing a road grade at Kailua Substation brought on *Pythium* growth failure of the varieties Molokai 3978 and 28-4867. The variety 28-1234 did not appear to be checked in growth in this environment.

Determinations made by the Chemistry Department indicated that the pH of the soil had been changed from pH 7 to 8.2 by the treatment. The aggravation

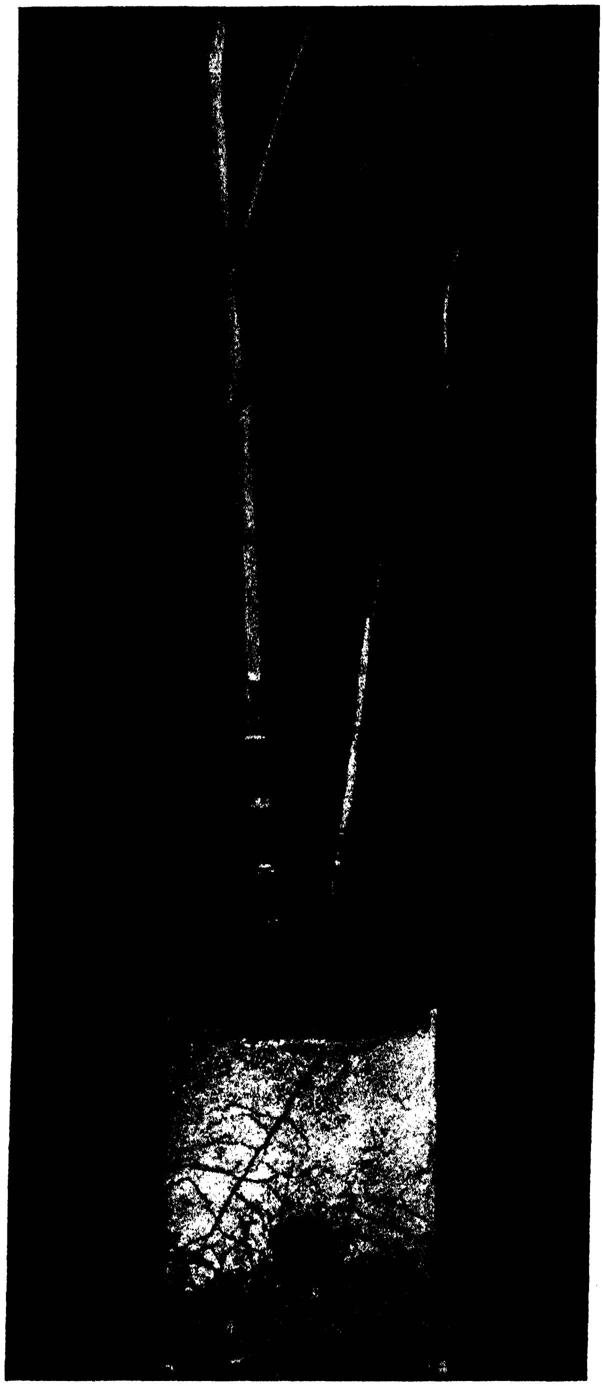

Fig. 24. D 1135. Compare with Figs. 22 and 23. One root was detoured into quartz sand containing "complete fertilizer" briquette prepared by the Chemistry Department.

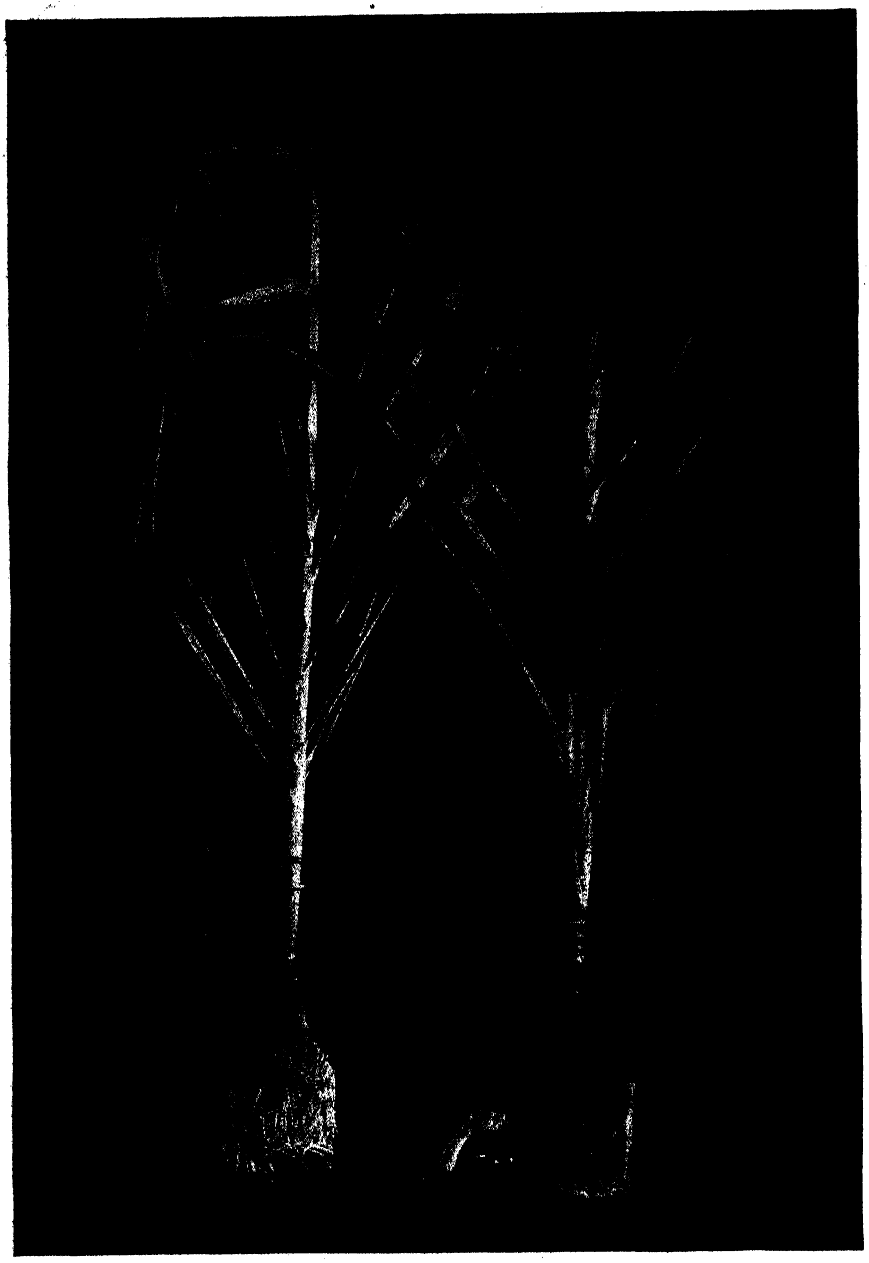

Fig. 25. D 1135. Discriminative root feeding. Both plants in minus-phosphate culture solution, the one at right having had one root in a solution of sodium phosphate for two months. *Pythium* root rot was severe in the plant at left. Phosphate from the one root apparently was sufficient to improve growth and prevent root rot of plant at the right.

Fig. 26. Root masses of P.O.J. 36 and D 1135, developed in three and a half months from short cuttings in tap water without addition of any nutrients. Water changed weekly.

of root rot was possibly due to unbalanced nutrients, and to deficiencies (e.g., of iron) rather than to an excess of calcium *per se*. Earlier pot experiments with soil from Waipio (island of Oahu) in which Lahaina failed consistently showed that applications of finely ground coral rock aggravated the rotting.

A pot experiment was conducted at the pathology plot, Honolulu, with the varieties Molokai 3978 and 31-4867. Soil from that locality was mixed with increasing amounts of calcium carbonate (tailings from Waianae Lime Co.) as shown below and planted with the two varieties. Each pot had about 30 pounds of soil.

Treatment

Calcium carbonate (pounds)...........	0	¼	½	2	3
Number pots of each variety...........	4	3	3	3	2

Growth of the variety Molokai 3978 was somewhat depressed even in the check and the depression was aggravated with the increase of calcium carbonate amendment. *Pythium* root rot was increasingly prevalent and correspondingly destructive. No root rot of 28-4867 was observed in the control series nor in

significant amount in any series except the last which contained 3 pounds of lime per 30 pounds of soil. The growth in this series was conspicuously depressed, the leaves yellow and abnormally dry and rolled.

The excellent growth of roots which was obtained in tap water without added nutrients, with fifteen cuttings consisting of five of each of the varieties, P.O.J. 36, D 1135 and Natal Uba, is worthy of mention. The cuttings were placed in tap water May 5, 1933, and the water changed once a week thereafter. The water in three jars of each series was acidified with sulphuric acid to a hydrogen ion concentration of 5.0; the others were left with pH 7.9 approximately. No *Pythium* root rot occurred in the growing period of 3½ months; Fig. 26 shows the remarkable mass of healthy roots which developed. The rootlets were of the fine type Martin reported (37) associated with nitrogen deficiency. Top growth was very slow and the leaves pale green throughout the period. Growth had apparently ceased at the end of about two months.

Martin (36) reports that when detached shoots were grown in standing tap water, a restricted root system was formed. The prevailing difference in root mass between Martin's experiment and the writer's is attributed to the difference in the amount of nutrients available in the cuttings as compared with that in the detached shoots. Martin's and the writer's experiments incidentally supplemented each other and contributed to our knowledge of the elemental factors associated with the development of roots resistant to *Pythium* attack.

The stored food of the cutting, which may be recognized as a balanced ration, has sufficed in this experiment for a moderate top growth and the development of an almost incredible mass of healthy roots. This indicates that "balanced" deficiencies do not lead to root rot and again raises the question as to the effect of balanced excesses of nutrients on the susceptibility of roots to *Pythium*. In other words, can excessive nitrogen, which is conducive to root rot of certain varieties, be balanced and rendered innocuous with phosphate and potash, etc.?

This question has not been thoroughly investigated. Cooke had found that certain phosphate-fixing soils responded to heavy phosphate applications, approximately five times the normal applications used in the Mitscherlich studies. Such large applications were not practicable. It was thought that smaller amounts of phosphate might serve to check the root rot, if the nitrogen supply was at a minimum. Mr. Cooke kindly conducted a Mitscherlich experiment with Sudan grass in "phosphate-fixing" soil from Field 26 K, Hamakua Mill Company, to investigate this point. Four series of eight pots each were included, the nitrogen applications being varied from "N" or standard practice in the Mitscherlich work as follows: ¼ N, ½ N, N and 4 × N; in each series the potash was standard but the phosphate was varied from standard or "P" to include 3 × P, 7 × P and 10 × P. It was soon evident that with less than standard nitrogen (N) application this element was a limiting factor in growth in this soil. There was no indication that the phosphate required to satisfy the soil and become useful to the plants could be reduced below Cooke's empirical "5 × P". The series of dry weights of the plants reported by him showed that the largest yield had been secured with 10 × the phosphate and 4 × the standard nitrogen application (10 P K 4 N) and the next largest 7 P K 4 N.

In the foregoing section of this paper, the theory of the determining influence of abnormal nutrition of the cane plant upon susceptibility to *Pythium* root-rot disease, advanced in 1928, is substantiated by experimental evidence obtained in soil and in water cultures. The clarification of the "root rot" and "growth-failure complex" of sugar cane has advanced rapidly in the cooperative studies with Cooke regarding phosphate-fixing soils. The contributions brought to our attention from time to time by Mr. Martin as *Pythium* root rot occurred in his water cultures, deficient respectively in one of the several elements essential to cane growth, greatly extended the scope of this synthesis. Where growth failure associated with *Pythium* root rot occurs in commercial fields, either a natural varietal susceptibility and/or a susceptibility acquired by abnormal nutrition is to be suspected.

Resume

The literature of the last decade shows an increasing recognition of the causal relation of species of *Pythium* to many obscure diseases of various plants including the grasses, more particularly root rot of sugar cane and of the cereal crops, corn and wheat. Beyond a discussion of the general aggravating effects of high soil moistures and low soil temperatures on the severity of the attack, the literature offers no definite information on the fundamental factors which determine the occurrence of the disease.

An investigation of the erratic occurrence of root rot of Lahaina cane in Hawaii, which finally was largely responsible for the elimination of this popular variety from commercial cane culture, required consideration of other factors than soil types, soil temperatures and moisture. The disease was not restricted to any types of soil, occurring wherever the variety was grown throughout the great diversity of environments on irrigated as well as unirrigated plantations and even on virgin lands as well as soils long in cultivation to cane. It was recognized that both moisture and temperature were of significance to the degree of injury but of secondary importance to factors which determined what particular areas would be affected. Unless increased susceptibility of this variety induced by some determinative factors of the environment other than moisture and temperature was present, the latter factors did not appear *per se* to be very important.

Varieties differed in their behavior to *Pythium* root rot but even the most resistant, D 1135, Yellow Caledonia and H 109, harbored the fungus to some extent so that it was difficult to offer convincing proof that the disease of the popular Lahaina was due to *Pythium* attack. The actual occurrence of the fungus within the roots of a variety considered susceptible did not necessarily result in root rot sufficiently severe to cause growth failure. It was necessary to presume factors which determined whether the rotting was restricted to a few roots, progressed slowly and was inconsequential, or became epidemic and destroyed all the roots as fast as they were formed, resulting in complete growth failure. A theory of susceptibility varying according to soil nutrients was adopted for the investigations. Excessive nitrogen for Lahaina as a prototype was first investigated. It was demonstrated that with applications of nitrogen considered moderate for other varieties, root rot resulted even in soils where Lahaina grew normally with small nitrogen applications. Then it was shown that even the resistant variety

H 109 was severely attacked by *Pythium,* following large applications of nitrogen to the soil. To produce this effect with H 109, nitrogen was required at rates which were decidedly uneconomical and greatly in excess of those which had been found to lower the quality of juice in the cane crop at harvest. Thus, it appeared that our standard variety for irrigated plantations was not likely to deteriorate as Lahaina had done, i.e., to succumb to *Pythium* attack as a result of excessive nitrogen fertilization. The effects of a combination of high nitrogen and low phosphate availability on standard canes sensitive to the latter have not been investigated.

It seems obvious that the ability of H 109 to use nitrogen may be one of the criterions of a superior cane. That its superiority over other seedling canes, first evident at Ewa Plantation, coincident with the use of increasing nitrogen in 1910 and again in 1912, in which this plantation was the pioneer, may have been due to the fact that elsewhere sufficient nitrogen was not applied to bring out its superior vigor. If we disregard root rot, which was a factor in the recognition of H 109 as superior to Lahaina, is the ability to use more nitrogen without detrimental effects in root rot or in deterioration of cane juice a criterion of superior canes? Can we predict without trial that some of these canes which seem to be equal to H 109 would not be superior if the conditions of culture were modified to suit them by the application of stimulative nitrogen beyond the amount which happens to be the maximum for H 109 and injurious to its juice quality?

Experiments at the pathology plot demonstrated that the growth failure factors in this soil for E. K. 28 were corrected by growing H 109 *without fertilizer* for two years, in the same furrows from which E. K. 28 had been removed, to lower the nitrogen content. The plot was replanted with E. K. 28, in the same furrows, and no evidence of growth failure has been observed in the following three years.

Subsequent investigation of the effect of nutrients on root rot has shown that in the phosphate-fixing soils of Hamakua, the fungus is enabled to destroy the roots of commercial varieties such as D 1135 and brings on growth depression; and that the condition can be corrected experimentally by chloropicrin treatment to eliminate the *Pythium* fungus, or by large applications of phosphate. Neither the chloropicrin treatment nor the phosphate applications required are economical for field use. Mr. Martin has shown that in water cultures of cane not only deficiencies of phosphate but also deficiencies of either calcium, magnesium, iron, potash, manganese, and sulphur were accompanied by *Pythium* root rot. Nitrogen deficiency, on the contrary, had the opposite effect of preventing its inception, or checking it in cultures where it was present before the deficiency was brought on.

If we disregard areas of soil where *Pythium* root rot is a factor with certain varieties as a sequel to abnormal nutrition, our crop cane is considered to be relatively free of root-pruning parasites and root-rotting organisms. In general, it is considered that root replacement by normally functioning cane plants as a result of the natural vigor of this crop nullifies the effect of *Pythium* and the minor agents of root destruction in commercial fields. In abnormal soils such as those of the phosphate fixing type and in other soils where excesses of certain chemical elements or deficiencies of those essential to normal growth occur, *Pythium* root rot may be expected to cause, or to aggravate, growth depression. In general,

under such conditions, selected cane varieties offer the economic way to meet the problem in the Territory of Hawaii.

Summary

1. A synthesis of facts obtained during the last few years of research is presented which shows that abnormal nutrition precedes root rot of sugar cane and Sudan grass by *Pythium graminicolum* Subramaniam, formerly called *P. aphanidermatum* (Edson) Fitz.

2. Cane varieties differ in susceptibility to *Pythium* root rot. They apparently differ also in their tendency to, and the resulting effect of, abnormal nutrition. A quality of resistance of certain varieties of cane is changed to varying degrees of susceptibility by modifying the nutritional environment.

3. Nitrogen in excess for the particular variety leads to susceptibility to *Pythium graminicolum* in virgin soil and in soils where the disease is not ordinarily observed.

4. Deficiencies of available phosphate promote *Pythium* root rot and growth failure of canes which are not particularly sensitive to increased nitrogen, and which grow well where Lahaina was a miserable failure and continues to fail in trial plots. H 109, D 1135 and Yellow Caledonia, for example, are particularly sensitive to low phosphate availability. P.O.J. 2878 appears to tolerate either high nitrogen or low phosphate availability. It is susceptible to *Pythium* root rot in certain fields at Puuloa, Oahu, but the accessory factors have not been determined.

5. In the phosphate-fixing soils studied, there is sufficient available phosphate to permit normal growth of Sudan grass, and young cane plants, when *Pythium* is eliminated by chloropicrin fumigation. Reinfection or inoculation of such soils with *Pythium*, after fumigation, induces growth depression. This artificially induced depression was overcome and normal growth induced again by adequate phosphate applications.

6. Martin reported that *Pythium* root rot was serious on cane grown in culture solutions deficient in either phosphate, iron, calcium, magnesium, potash, manganese or sulphur.

7. Experiments indicate that excesses of calcium and probably of the other bases, magnesium and sodium, and of toxic salts of aluminum and iron in the soil, favor root rot. Harmful base ratios and unfavorable balances of nutrients are the probable result, e.g., a deficiency of iron or phosphorus *et al.* The increase of susceptibility is to be considered as due to such deficiencies rather than to any direct effect.

8. Soil moisture and temperature are important factors in determining the degree of severity of root rot when susceptibility of the roots to *Pythium graminicolum* is present, either the natural weakness peculiar to certain varieties or the susceptibility acquired by stronger varieties as a result of abnormal nutrition. Abundant soil moistures and relatively low soil temperatures (70° F. or lower) favor root destruction by *Pythium* while, at the same time, the low temperature restricts root replacement.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD JUNE 18, 1934 TO SEPTEMBER 4, 1934

Date	Per Pound	Per Ton	Remarks
June 18, 1934	3.025¢	$60.50	Philippines, 3.00; Puerto Ricos, 3.05.
" 19	3.13	62.60	Cubas.
" 20	3.075	61.50	Philippines, 3.05; Puerto Ricos, 3.10.
" 21	3.11	62.20	Philippines, 3.10; Philippines, Puerto Ricos, 3.12.
" 22	3.165	63.30	Cubas, Puerto Ricos, 3.15; Cubas, 3.18.
" 28	3.15	63.00	Puerto Ricos.
" 29	3.1667	63.334	Puerto Ricos, Philippines, 3.15; Cubas, 3.17, 3.18.
July 6	3.15	63.00	St. Croix.
" 18	3.17	63.40	Cubas.
" 20	3.20	64.00	Puerto Ricos, 3.18; Cubas, 3.22.
" 23	3.175	63.50	Puerto Ricos, 3.17, 3.18.
" 26	3.18	63.60	Cubas.
" 31	3.20	64.00	Cubas.
Aug. 2	3.225	64.50	Philippines, 3.18; Cubas, 3.27.
" 3	3.30	66.00	Cubas.
" 7	3.32	66.40	Cubas.
" 10	3.20	64.00	Puerto Ricos.
" 24	3.22	64.40	Cubas.
" 29	2.70	54.00	Cubas.
" 30	2.75	55.00	Cubas.
Sept. 4	2.86	57.20	Cubas.

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